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STUDIES ON HOUSEHOLD SEWAGE DISPOSAL SYSTEMS. PART III

S. R. Weibel, et al

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1954

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Studies On Household Sewage Disposal Systems

PART III

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

150

Studies on

Household Sewage Disposal Systems

Third in a series of research reports on individual sewage disposal systems

by

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PART III. Multicompartment Tanks
Single-Compartment Tanks
Sludge and Scum Accumulation
Appraisal of Soil Absorption Capacity
Clogging Characteristics of Septic Tank Effluent
Zeolite Softener Salts
Ground Garbage
Synthetic Detergents
Evapotranspiration, Plant Growth
Distribution Appurtenances, Servicing Aids, "Cleaners"

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Sanitary Engineering Services
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio
1954

I

Public Health Service Publication No. 397

(This book has been given a P. H. S. Publication number for the convenience of readers, even though it is part three of a study and the previous parts were not so numbered. Both previous parts were published before the practice of numbering all such publications was begun)

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II

Preface

This report, the third progress report of the series, *Studies on Household Sewage Disposal Systems*, mainly concerns studies conducted during the period July 1949 to July 1953, when the laboratory work was terminated. Studies made prior to July 1949 were reported in Parts I and II.

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Introduction

SPONSORSHIP

The studies reported herein were initiated July 1949 pursuant to agreements for fiscal years 1950 and 1951 between the Housing and Home Finance Agency and the Public Health Service, and are a continuation of a broad program of studies on household sewage disposal systems inaugurated November 1946 under the sponsorship of the (then) National Housing Agency. The studies reported herein were jointly financed by H. H. F. A. and P. H. S. through June 1951, and by P. H. S. after that date.

PREVIOUS REPORTS

The progress reports, "Studies on Household Sewage Disposal Systems," Part I, 1949 (1) and Part II, 1950 (2), Public Health Service, Environmental Health Center, dealt with studies on thirteen items up to July 1949, which were considered sufficiently advanced in status to be released with proper qualifications.

THIS REPORT

This report is the third in the series. The work covered was essentially that done July 1949 through June 1953, the terminal date of the laboratory work. As in the case of the previous reports (1, 2), this report is considered a progress report.

PERSONNEL

The project operates as one of the activities of the Sanitary Engineering Center at Cincinnati under the administrative direction of Sanitary Engineer Director V. G. MacKenzie, officer in charge. The staff of the project included the following for various periods of time during July 1949 to July 1953:

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Sheehy, J. P.	S. A. San. Engr.
Carter, M. W.	S. A. San. Engr.
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ACKNOWLEDGMENTS

Grateful acknowledgment is made of the valuable guidance by Dr. H. A. Thomas, Jr., of Harvard University, Special Consultant to the Sanitary Engineering Center in methods and statistical handling of data and in reviewing the report; also of the advice, reviews and many other aids furnished by the staff at the Center during the course of the work.

Application of Research Results

"Studies on Household Sewage Disposal Systems, Part III, 1954," the third progress report of a series, deals with continuance of studies on home septic tank details, including multicompartmentation arrangements, capacity, shape, depth, surface area, outlets, sludge and scum accumulations, effect of flow variation; soil absorption factors, including appraisal of absorption capacity, physical, chemical, and biological clogging behaviors, intermittent dosing; and effects of water softener brine and ground garbage. Additional undertakings reported include studies on detergents, evapotranspiration as an influence in effluent disposal, flow distribution devices, sludge and scum gaging devices, tank improvements to facilitate maintenance, and the effect of caustic soda.

Conclusions regarding design which are believed to be warranted are as follows:

1. Properly designed multicompartment household septic tanks give as good or better performance than single-compartment tanks of the same total capacity.

(*a*) Two-compartment tanks with one-half or two-thirds of their capacity in the first compartment give better performance than single-compartment tanks of the same total capacity, except at extreme depth mentioned in (*e*).

(*b*) Two-compartment tanks with one-third of their capacity in the first compartment; 3-equal-compartment tanks; and 4-equal-compartment tanks give at least as good performance as single-compartment tanks of the same total capacity.

(*c*) In a two-equal-compartment arrangement, there is no difference in performance between rectangular and cylindrical shapes, if equal solids storage capacities are provided.

(*d*) In a 4-equal-compartment arrangement, a 28½-inch liquid depth gives somewhat better performance than a 62-inch liquid depth.

(*e*) A 2-equal-compartment arrangement with 120-inch liquid depth performs as well as, but no better than, a single-compartment tank of the same total capacity.

2. Single-compartment, 500-gallon, rectangular tanks may be expected to give good performance at liquid depths ranging from 28½ to 64 inches, with a tendency toward somewhat better performance at the shallower depths.

3. Minimum distances between the bottom of outlet device and top of sludge (sludge clear space), and bottom of scum (scum clear space) as defined on page 29, develop, beyond which sludge or scum will discharge. A tank should be cleaned when either distance is approached.

(*a*) For 500-gallon tanks of constant horizontal cross-section and liquid depths ranging from 28½ to 64 inches, the average minimum sludge clear space generally should not exceed the distances given in table 22, page 31.

(*b*) A reasonable value for minimum scum clear space is three inches.

4. Maximum use can be made of tank capacity to store sludge and scum if a balance is obtained between the space allotted to sludge and to scum, through proper design of penetration and projection of outlet device. Such design may be based on the following:

(*a*) The space available for storage of sludge and submerged scum for tanks of constant horizontal cross-section is equal to the difference between tank liquid capacity and total clear space volume.

(b) A reasonable value for the ratio of submerged scum, to total submerged scum plus sludge, is approximately 0.27.

(c) On the average, approximately 27 percent of the total scum accumulation floats above the water line.

(d) A reasonable allowance for tide rise during intermittent flow is about 1½ inches.

(e) Minimum distance from bottom of scum to bottom of outlet device is three inches.

5. The rate of accumulation of scum and sludge can be approximated by equations shown in table 25, page 41. The wide spread between average and greater coverage values indicates difficulty in attempting to generalize on cleaning intervals. Consideration should be given to periodic inspection and gaging of each installation for economic maintenance.

6. Soil survey maps and reports published by agricultural groups, and visual inspections of the soil profiles, noting particularly texture, structure, and color, are valuable aids in preliminary qualitative appraisal of sites for soil absorption systems.

7. There is a need for a fundamental and objective percolation test procedure for appraising sites for soil absorption systems. An objective test is desirable to eliminate personal judgment. A test providing opportunity for saturation and swelling is indicated for about 50 percent of the soils in this country, to insure that rates obtained reflect absorption field moisture conditions. Shortcut tests developed for local conditions should be checked against the fundamental test.

8. A fundamental and objective test procedure is suggested on pages 61 to 63.

9. Rates obtained with the suggested test are reasonably applicable to the original Ryon allowable sewage loading relationship and to design area tables on pages 3 and 63. This is not true of many current test procedures which involve personal judgment. In such cases, the suggested test may give slower but more representative rates.

10. Reduction in the amount of suspended solids in effluent applied to a soil reduces soil clogging.

11. Reduction of biologic activity in effluent applied to a soil causes increased soil clogging.

12. Chemical composition of effluent may influence soil clogging. Increased sodium ratios may cause increased clogging in structured type soils.

13. Clarified fresh sewage causes more soil clogging than normal septic tank effluent. Aging of effluent tends to reduce its clogging behavior.

14. Intermittent dosing of effluent to soils at approximately four-month intervals will tend to maintain soil absorption capacity at a higher level than will continuous dosing. The report is not conclusive as to the optimum interval.

15. Discharge of water softener regeneration brines containing 22 pounds of mixed salts, as often as once a week, to a well-seeded septic tank has no adverse effect on tank performance. However, the effluent causes more damage to soil structure than does normal effluent. Damaged soil structure may result in some shortening of absorption field life.

16. Ground garbage may be disposed of along with the normal household wastes in septic tank-soil absorption systems, when tanks are adequately seeded with ripe sewage sludge and tank and soil absorption area design sizes are adequately adjusted. Although this report is not conclusive on the quantitative values, it is thought that reasonable allowances are 50-percent increase in tank capacity and increased soil absorption areas, as shown in item 18 below.

17. Increased water consumption in automatic sequence washer equipped homes is indicated. The increase is not likely to adversely affect tank performance, but will necessitate increased soil absorption areas, as shown in item 18 below.

18. Suggested soil absorption field design areas, calculated from available information, are presented in the table following:

Suggested soil absorption field design areas

Percolation rate (time required for water to fall 1 inch, in minutes)	Required absorption area (square feet of absorption trench bottom per bedroom)			
	Without garbage grinder or automatic washer [1]	With garbage grinder [2]	With automatic washer [3]	With both garbage grinder and automatic washer [4]
2 or less	50	65	75	85
3	60	75	85	100
4	70	85	95	115
5	75	90	105	125
10	100	120	135	165
15	115	140	160	190
30	150	180	205	250
45	180	215	245	300
60	200	240	275	330
Over 60	Unsuitable for shallow absorption system. Investigate for seepage pit or subsurface filter arrangement.			

NOTE.—The above areas are the estimated 99 percentile, or higher, values (rounded), calculated by statistically combining the following factors:

[1] Allowable sewage loading values for each percolation rate, derived from Ryon (16, 17) and P. H. S. (2) data, with winter water consumption and home-occupancy values from this report.

[2] Factors noted above, with garbage area increases derived from soil core data in this report.

[3] Factors noted in [1] above, with increase in water consumption in automatic sequence washer equipped homes, as indicated in this report.

[4] Factors noted in [1],[2], and [3] above.

19. Based on tests of one alkyl aryl sulfonate type anionic syndet, addition in quantities approximating average usage in a four-load wash once a week, to a sewage containing residual household syndets, will not seriously interfere with biological activity, nor with suspended solids nor grease removal in a 500-gallon septic tank.

20. None of seven brands of household syndets interfere with normal digestion in quantities representing average household use for all purposes, but several of the brands noticeably interfered in quantities representing more than average use.

21. An alkyl aryl sulfonate type anionic syndet in laundry water, or in septic tank effluent, shows no difference in short-time soil clogging behavior than a soap, but does slightly more damage to soil structure.

22. Some proprietary products purported to "clean" septic tanks contain sodium hydroxide or potassium hydroxide as the active agent. Twenty-five pounds of sodium hydroxide added to a 500-gallon septic tank results in sludge bulking, radical change in pH, and inhibition of digestion. The resulting effluent will severely damage soil structure and cause accelerated clogging. Potassium hydroxide in septic tank effluent causes similar, but less severe, soil clogging.

23. Advantage may be gained in soil absorption system operation from vegetation over the absorption field area. The advantage accrues particularly during the growing season and varies with geographical location.

24. It appears from studies by others that an inlet baffle in a distribution box is desirable. Clay tile tees and wyes, even when carefully laid, are poor flow-dividing devices.

25. A strip of turkish toweling on a stick and a stick with a hinged weighted flap are useful devices for periodic gauging of sludge and scum respectively, in order to determine when a tank must be cleaned. Extension of septic tank inspection and servicing openings to within six inches of the ground surface appears useful.

Summary

A. FURTHER STUDIES ON MULTICOMPARTMENT TANKS

1. Three rectangular tanks of approximately 500 gallons liquid capacity were subdivided into 1, 2, and 3 equal-compartment tanks, respectively. Based on ability to remove suspended solids and to store sludge, the 2-compartment tank gave improved performance over both the single- and 3-compartment tanks. Performance of the 3-compartment tank was equivalent to that of the single-compartment tank.

2. A 553-gallon tank, consisting of two equal vertical cylinders, performed as well as as a two-equal-compartment, 500-gallon, rectangular tank. The former retained more sludge than the latter by an amount approximately equal to the difference in capacity.

3. A 673-gallon tank separated into 4 equal-capacity, round, vertical compartments gave the best performance, as measured by ability to remove suspended solids and to store sludge. The increase in sludge accumulation over that of the 2-compartment tanks was of the same magnitude as the increase in capacity. A marked reduction took place in percentage of volatile matter in sludge contained in the last compartment as compared with that contained in the first.

4. In a properly designed multicompartment tank, a major part of the agitation due to digestion appears to be exerted in the first compartment, resulting in less interference with sedimentation and compaction in subsequent compartments.

5. The effect of compartment proportions was observed for 94 weeks in three 500-gallon, 2-compartment, rectangular tanks, differing only in proportion of total capacity contained in the first compartment.

6. Tanks with one-half and two-thirds of total capacity in the first compartment removed 67 and 68 percent, respectively, of raw sewage suspended solids added. A tank with one-third of its capacity in the first compartment removed 56 percent of the suspended solids during the same period, roughly equivalent to the performance of a single-compartment tank.

7. Although maximum sludge storage capacities were not reached, more sludge was retained in tanks having equal and large first compartments, than in a tank with a small first compartment.

8. Less suspended solids were found in supernatant liquors of the second compartments of two-compartment tanks than in the first. Supernatant liquor suspended solids from last compartments contained a greater proportion of volatile matter than those from the first compartments in the tanks having the equal and the large first compartment. In the small-first-compartment tank, the trend was reversed.

9. Performance of a 500-gallon, two-compartment, vertical, cylindrical septic tank of about

120 inches liquid depth was evaluated. Based on suspended solids removed during a 65-week period before failure, efficiency was approximately 60 percent. Maximum sludge accumulation was approximately 29.4 cubic feet. This performance approximates that of a single-compartment tank, but would be below that of a less radically designed two-compartment tank.

10. The performance of 2 experimental multicompartment, 500-gallon septic tanks was compared for a period of 53 weeks to determine the effect of liquid depth on performance. Each tank consisted of 4 vertical cylindrical compartments in series. Liquid depth in the one was 28.5 inches, in the other, 62 inches.

a. Suspended solids removal efficiencies were 79 and 75 percent for the 28.5- and 62-inch-depth tanks respectively during the first 39 weeks, under influence of fall and winter temperatures.

b. Under the influence of rapidly rising and exceptionally high summer temperatures, the 62-inch depth tank discharged sludge solids, and registered negative suspended solids removal efficiencies. The 28.5-inch-depth tank maintained relatively high removals during this same period.

c. The 28.5-inch liquid depth tank gave better year-round performance than the equal capacity 62-inch liquid depth tank.

B. FURTHER STUDIES ON SINGLE-COMPARTMENT TANKS

1. Four rectangular 500-gallon single-compartment septic tanks, with liquid depths 28½, 36, 48, and 64 inches, respectively, were operated simultaneously, all under similar circumstances, in the laboratory.

2. Good performance in suspended solids removal and sludge storage was obtained in the 28½-, 36- and 64-inch-depth tanks, with differences in performance favoring the shallower depths. The performance of the 48-inch-depth tank in this experiment was substandard to that of identical tanks operated in other experiments during the project. Efforts to determine the reason for the behavior were fruitless.

3. Field data indicated that accumulating sludge approaches a limiting level below the bottom of an outlet fixture, and that this minimum distance ("sludge clear space") might be approximately 1 foot.

4. Laboratory study of the effect of scour on sludge indicated that the sludge clear space which developed remained approximately constant at feed rates of 10 to 30 gallons per minute. Sludge clear space was affected by temperature, increasing from approximately two-thirds of a foot in winter to approximately 1 foot in summer.

5. Changing the penetration of the outlet device did not affect sludge clear space.

6. Minimum sludge clear spaces developing in eleven 500-gallon experimental septic tanks, all having straight vertical sides, indicated that minimum sludge clear space varies inversely with tank surface area.

7. For straight vertical side septic tanks of approximately 500 gallons liquid capacity, with surface areas ranging from 12.5 to 28.1 square feet, the probability is 95 percent that mean minimum sludge clear space will not exceed values given in table 22, page 31.

8. Three inches, arbitrarily chosen as a reasonable allowance for scum clear space, added to the sludge clear space distances of table 22, provide an estimate of total minimum clear space. Total tank liquid capacity minus clear space volume equals the below-water scum and sludge storage capacity of a tank.

9. Two trial runs were made on a single-compartment 123-gallon septic tank, started in each case without seeding. The first trial started in the winter, the second in the spring. Each trial ran 60 weeks.

10. The winter start was characterized by an acid digestion phase, evidenced by low pH's, excessive scum, and offensive odors. During the spring start, lag in digestion appeared shorter, and no excessive scum, odors, or low pH's developed.

11. In both winter and spring starts, the tank failed, after rapidly accumulating sludge over a winter, with onset of warmer spring and summer temperatures. The discharge of sludge accompanying seasonal temperature variation appeared much more severe in the 123-gallon tank as compared with that in 500-gallon tanks.

C. SLUDGE AND SCUM ACCUMULATION

1. Although sludge and scum accumulation behavior may be determined on a per person basis where person loading history is available, its application for design and servicing considera-

tions must bridge the gap between residences of known history and a proposed residence.

2. Per person sludge and scum accumulation data derived from field survey, together with history of person occupancy and time in service, were used to develop equations for scum and sludge accumulation on a bedroom basis.

3. The equations for such accumulations are presented in table 25, p. 41.

4. Maximum use is made of tank capacity to store sludge and scum when a balance is obtained between the volume allotted to scum and that allotted to sludge. For this reason, the ratio of submerged scum to total submerged accumulation is an important design consideration. A reasonable ratio of submerged scum to total submerged accumulation was found to be 0.27.

5. A comparison of 15 "conventional washer" against 15 "automatic washer" homes in Duval County, Fla., revealed that there was an increase in water use in the "automatic washer" homes. Using previous field data, a multiple correlation was made between the rate of accumulation as the dependant variable, and persons, capacity, and water use as 3 independent variables. The coefficients for capacity and persons were found to be highly significant, but no significance could be attached to that for water use. Thus, variations in water consumption, within the range 8 to 149 gallons per person per day, have no effect on septic tank solids retention. However, provision for the increased volumetric loading on the soil absorption system should be made. In 95 out of 100 cases, the increase would not be expected to exceed 93 gallons per bedroom per day.

6. Laboratory observations indicate that performance may be more sensitive to the amount of sewage received in each intermittent dose than to the daily overall quantity of sewage received. More investigation is needed on this.

7. The combined effect of time, persons, and capacity on submerged scum and sludge accumulation was investigated, using a multiple correlation. The equation developed, applicable within the range of variables indicated in table 33, is:

$$y=3.4(t)+2.2(p)+4.0(c)-20.9$$

where

y=total submerged scum and sludge accumulation, in cubic feet.

t=time in service, in years

p=number of resident persons

c=capacity, in hundreds of gallons $\left(\frac{\text{gallons}}{100}\right)$

D. APPRAISAL OF SOIL ABSORPTION CAPACITY

1. The availability of soil literature, maps, and surveys and their value in qualitative appraisal of soil absorption systems are discussed.

2. Texture, structure, and color are properties of a soil which may be used in a qualitative manner to predict absorption capacity. Clues for their recognition and interpretation are given. Quantitative information must be obtained thru percolation test.

3. A review of studies of infiltration and percolation in related fields points out the need for prolonged test procedures to insure soil saturation and soil swelling. Duration of test depends on the anticipated problem for which rates are determined.

4. Study of percolation test modifications demonstrate the rate reductions that take place with elapsed time of testing and emphasize the importance of soil soaking with opportunity for swelling in order to approach equilibrium rate values.

5. The studies demonstrate that varying the horizontal dimension of the test hole from 4 to 12 inches does not significantly affect measured rates.

6. The variability of soil over one small area, and consequently the need for replication of percolation tests in an area, is demonstrated.

7. Limitations of percolation tests and the influence of other soil conditions, particularly ground water and impermeable layers, are discussed.

8. In formulating percolation test data and developing shortcut test procedures, it should be kept in mind that equilibrium rates develop only after soil swelling is essentially complete.

9. As written, most current percolation test procedures involve the personal judgment of the operator. A need for a fundamental and objective test is apparent and desirable, to eliminate, for example, personal judgment as to what is considered "wet the soil," "equilibrium rate," "constant rate," etc. A rigid test is, moreover, essential in most soils in the United States in order to insure saturation and opportunity for swelling, so that rates representative of the problem condition may be obtained. Such a test is highly desirable where no testing experience is available. As experience is gained, a fundamental test may be used to develop modified or shortcut methods to meet local conditions.

10. A fundamental and objective test procedure is suggested on pages 61 to 63. Rates obtained with this test are reasonably applicable to the original Ryon allowable loading relationship and to the table on page 63. This is not true of many current test procedures which involve personal judgment. In such cases, the suggested test may give slower, but more representative, rates.

11. Taking into account recent water-consumption data, effects of garbage-grinders and automatic sequence washers, the original Ryon allowable sewage loading data, and additional data on clogged systems and utilizing modern statistical approaches, a design area table is presented on page 63.

E. FURTHER STUDIES ON CLOGGING CHARACTERISTICS OF SEPTIC TANK EFFLUENT

1. Characteristics of septic tank effluent which influence soil clogging have been considered as physical, chemical, and biological. In the study of these factors, a number of soils available in the Cincinnati vicinity were selected to represent a wide range in absorption properties.

2. Clogging of soil cores was found to be directly related to the amount of suspended solids applied.

3. A review of the literature indicates that the chemical quality of irrigation water must be carefully controlled to prevent damage to soil water absorption properties. The sodium ratio (ratio of sodium to base cations, calcium, magnesium and sodium) is considered the critical factor. Waters in which the ratio is 65 percent or higher may be considered of poor quality, 50 to 65 percent of doubtful quality, and less than 50 percent generally satisfactory.

4. Literature also indicates that the sodium ratio in sewage treatment plant effluent may increase over that of the raw water supply.

5. Addition of calcium to septic tank effluent dosed to soil cores resulted in decreased clogging, while addition of sodium resulted in increased clogging as compared to normal effluent. The effects were more pronounced in well structured soils.

6. Effluent with reduced biological activity caused more clogging than normal effluent, while reduction of both biological activity and amount of suspended material applied caused less clogging.

7. Filtered fresh sewage caused more clogging, and well aged effluent caused less clogging, than normal septic tank effluent.

8. A field study, conducted to further investigate concepts of soil clogging obtained in laboratory experiments, confirmed that biologic activity in effluent is beneficial in decreasing clogging.

9. Allowing field test holes to rest for 120 days, after 112 days of effluent dosing, resulted in partial recovery of absorption capacity.

10. Soils dosed with effluent exhibited a more stable structure than when dosed with tap water. This effect is comparable to the improvement of surface soils by the addition of manure or plant residues.

11. In one soil on a sloped site the major part of seepage was observed to be lateral.

F. FURTHER INVESTIGATION OF EFFECT OF ZEOLITE SOFTENER SALTS

1. A 22-pound mixture of calcium, magnesium, and sodium chloride in the proportion and discharge pattern to be expected from regeneration of a household-type water softening unit was discharged to a laboratory septic tank once each week. No adverse effect on the performance of the tank was noted during the 28 weeks of salt additions. Salt concentration increased near the bottom of the tank during cold weather, but with the advent of warm weather the tank effectively purged itself of salt.

2. An investigation of the viability of sludge taken from the tank receiving salt demonstrated that microbiota had become acclimated to a saline environment. At a 1.0 percent mixed salt concentration, the seeding activity of a normal sludge was strongly inhibited, while the same concentration exerted little or no influence on the seeding activity of the salt sludge. At concentrations of 1.5 percent and greater, both sludges were inhibited, the salt sludge to a lesser extent than the normal sludge.

3. The tank used for the experiment was well seeded with digesting sludge and had been in normal operation for a long period prior to the first salt additions. Results obtained may not be applicable to a new tank started without seed material and receiving water softener regeneration wastes before natural seed has an opportunity to develop.

4. Bottle experiments to determine the effect of regeneration salts from a household-type water

softening unit on digestion of a sewage-sludge mixture show that:

(*a*) A 1.2 percent concentration of the mixed salts produced a 9½-day lag in digestion.

(*b*) After the initial lag period, digestion started and proceeded in a normal manner.

(*c*) No appreciable lag redeveloped when supernatant liquor was removed and test bottles were recharged with sewage containing sufficient mixed salts to produce a 1.3 percent concentration.

(*d*) Results indicate an adjustment of microbiota to the saline environment investigated.

5. A study of soil clogging produced by effluent from the tank receiving softener salts indicates that early percolation rates are maintained at a higher value with salt effluent than with normal effluent, but that more damage is done to soil structure by the salt than by the normal effluent. In that stability of structure to slaking by water is an index of sustained permeability, damage to structure may be a more important clue to long-run behavior than results of short-run percolation tests.

G. STUDIES ON GROUND GARBAGE

1. Indications from studies in the literature are that addition of ground garbage increases solids load considerably; that supernatant liquors (effluents) are likely to contain more total solids than when sewage only is treated; that mixtures of ground garbage and sewage, approximating community production ratios on a volatile solids basis, may be successfully digested in the presence of sufficient ripe sewage sludge seed.

2. An experimental study in 500-gallon septic tanks indicated that effluent from a tank dosed with sewage and ground garbage was lower in suspended solids than a sewage dosed control tank during the first 7 months of a 10-month run. A reversal of this trend developed for the last 3 months of the run with rising temperatures and increased digestion activity.

3. In the presence of ample amount of ripe sewage sludge, garbage tank effluent pH's were about the same as those of a sewage dosed control tank.

4. Effluent volatile suspended solids ratio was slightly higher for a tank receiving ground garbage and sewage than for the sewage dosed control tank throughout a 10-month experimental run.

5. Preliminary results from an additional 2⅓-year period of experimental operation indicate that, on the average, the effluent suspended solids concentrations for the garbage and nongarbage tanks were about equal.

6. Field examinations of 39 home septic tank-soil absorption systems in Duval County, Fla., 16 of which received ground garbage, were made.

7. During some 3½ years of operation, increases in average annual sludge and scum accumulations in tanks receiving garbage, over nongarbage tanks, averaged 77 percent. The major increase was in the scum accumulation, averaging approximately 210 percent. The increase in sludge accumulation averaged 31 percent.

8. Median pH's in septic tank supernatant liquor and sludge were 6.5 and 6.8, respectively, for garbage tanks, and 6.8 and 6.9 for nongarbage tanks. The tendency toward lower pH's in the garbage tanks persisted after 3½ years of operation at the relatively high temperatures of the Florida area.

9. Preliminary analysis of soils data indicates that, on the average, percolation rates of soil cores taken from used trench sections of garbage systems were slower than those from nongarbage systems. A slightly greater increase in organic matter content was noted in the soils from garbage systems. No differences in grease content were found.

10. In laboratory studies, data from eleven paired soil cores, representing five soils, show a definite trend for effluent from a septic tank receiving ground garbage and sewage to cause greater clogging than effluent from a tank receiving normal sewage only.

11. Based on the percolation rates of paired soil cores after clogging, the garbage tank effluent dosed cores would require, on the average, about 11.8 percent larger areas, in order to absorb the same volume of effluent as the nongarbage cores. The standard deviation of the increase in area is 21.2 percent.

H. STUDIES ON SYNTHETIC DETERGENTS IN THE SEPTIC TANK-SOIL ABSORPTION SYSTEM

1. Once each week for 27 weeks, 85 grams of an anionic synthetic detergent, containing 40 percent sodium alkyl aryl sulfonate, were added to each of four consecutive Monday morning feeds of raw sewage to a 500-gallon septic tank. The performance of this tank was compared with a control tank receiving sewage only.

2. Considering the normal variation in suspended solids removals previously observed in 500-gallon tanks, the syndet did not interfere with suspended solids removal performance.

3. Observations on biologic activity, volatile solids and seasonal tank upsets, indicated some interference with digestion by the syndet, although not serious.

4. Effluent from the syndet tank contained slightly higher concentrations of grease.

5. The same syndet was applied in concentrations ranging from 50 to 500 p. p. m. active agent to digestion bottles containing a fresh-sewage and ripe-sludge mixture. Although slight lags developed, there was no appreciable interference with gas production at concentrations of 150 p. p. m. or lower. At concentrations of 200 p. p. m. and greater, the rate of gas production was retarded. For this product, the 150 and 200 p. p. m. active product concentrations are equivalent to 375 and 500 p. p. m. whole product concentrations, respectively.

6. Seven household brands of syndets were added to digestion bottles containing a fresh-sewage and ripe-sludge mixture in concentrations reflecting first, more-than-average and second, average family usage. Several of the brands noticeably interfered with normal digestion at higher syndet usage, but none of the seven brands interfered seriously at average usage.

7. Tap water solutions of an anionic syndet and grease, which did not have the complicating clogging influence of solid particles, caused less soil core clogging than did comparable solutions of a household soap and grease. After several weeks of treatment, the syndet solutions actually caused an increase in percolation rates. The syndet solutions also tended to improve percolation rates of soil cores previously clogged with soap solutions.

8. Increasing amounts of grease in soap solutions caused increased clogging, whereas the amount of grease in syndet solutions showed no apparent correlation to soil clogging.

9. Home laundry waste water containing either soap or syndet caused greater soil core clogging than did effluent from a septic tank receiving community sewage. There was no difference in the clogging behavior between soap laundry water and syndet laundry water as judged by reduction in core percolation rates. Soil aggregate stabilities of the syndet treated cores, however, tended to be slightly lower, which, from a long time viewpoint, indicates that the syndet may be slightly more damaging than the soap.

10. There was no difference in soil clogging behavior between septic tank effluents containing added amounts of either soap or syndet.

11. In tap water solutions, without the complicating clogging influence of solids, syndet caused less soil clogging than soap, in field auger holes. No consistent difference was noted in their effect on aggregate stability.

I. EVAPOTRANSPIRATION AND PLANT GROWTH IN RELATIONSHIP TO SOIL ABSORPTION SYSTEM OPERATION

1. Observations on a number of soil absorption systems in the Cincinnati area indicated that soil moisture lost through evapotranspiration can be an important factor in the successful operation of systems.

2. A review of literature indicates that the primary value of evapotranspiration would vary with climate and would be limited to the plant-growing season and to areas in which the water table is deeper than four feet.

3. In absorption trenches, roots were observed to be confined primarily to the gravel fill below the tile distributor. This tends to disprove the idea that roots in a distribution system are a serious cause of failure.

4. Root growth may be an important factor in the production of stable soil granulation and increased soil pore space which tends to improve absorption characteristics.

J. SUPPLEMENTAL INVESTIGATIONS

1. An engineering firm reported high distribution efficiencies for a 12-inch diameter (approximately), hexagon-shaped distribution box, having 5 outlets and influent baffle, on the basis of experimental runs. Although outlets were 2 inches above the floor, the baffle was found necessary to obtain the performance reported.

2. In a test of a carefully laid clay tile tee as a flow divider, approximately 85 percent of the flow was through 1 leg. Similarly poor results were obtained when the tee was reversed.

3. A test of 2 carefully laid clay tile wyes as flow distributors in a herringbone arrangement was conducted. At a 2-percent slope, equal distribution was obtained from the wyes, but only about

14 percent of the total flow was diverted. At a 0.5 percent slope, the first wye diverted 4 times as much flow as the second. Combined diversion in this case was 58 percent of the total flow.

4. Because of extreme variation in the rate of sludge and scum accumulations, it is important that periodic gauging be made to determine when a tank must be cleaned. A strip of turkish toweling on a stick and a stick with a hinged weighted flap seem practical for home use in this connection.

5. Recent experience in the field indicates that septic tank inspection and servicing openings which are extended close to the ground surface are proving useful.

6. One chemical septic tank "cleaner" labeled as containing sodium hydroxide, on chemical analysis, calculated as sodium hydroxide, was found to contain the equivalent of about 97 percent sodium hydroxide.

7. Addition of a strong solution of sodium hydroxide to a model septic tank caused bulking of the sludge layer, the sludge changing from a material with distinct granular texture to one with the consistency of a heavy motor oil.

8. Addition of 25 pounds of sodium hydroxide, a manufacturer suggested dose of "cleaner," to a full-sized septic tank caused an immediate bulking of the sludge layer. The pH of the effluent rose to 12.5 and remained above 11.0 for five days and above normal for 58 days. It caused no appreciable difference in the removal of suspended solids, but there was evidence that biologic activity or digestion was inhibited.

9. In bottle digestion experiments, interference with digestion of sewage-sludge mixtures developed when pH was raised to 10.0 or above by the addition of sodium hydroxide.

10. Concentrations of sodium hydroxide in effluent approximating those which might develop from addition of 25 pounds of sodium hydroxide to a septic tank caused immediate clogging of soil cores, accompanied by a destruction of soil structure. Concentrations as low as 380 p. p. m. caused significant clogging.

11. Potassium hydroxide in septic tank effluent caused soil clogging in concentrations of 750 p. p. m. and above. The damaging effect was less severe than that of sodium hydroxide.

SECTION A

Further Studies on Multicompartment Tanks

Equal Compartments, Cylindrical and Rectangular Shapes

INTRODUCTION

In a previous report (1) on these studies, it was shown that multicompartment tanks provided a higher degree of suspended solids reduction than single-compartment tanks of roughly equal capacity. Multicompartment tanks observed in the early study were cylindrical types.

Three identical rectangular shells 3 feet wide, 6 feet long, and 4 feet liquid depth were used. The first of these, tank 9A, was left as a single-compartment "Joint Committee" type; the second, tank 7A, was divided into 2 compartments with a 2-inch transverse partition at the midpoint; and the third, tank 19, was divided into 3 compartments with partitions at third-points. Operation of tank 3 (2-compartment) and tank 4 (4-compartment), the vertical cylinder types previously reported (1), was also resumed.

Preliminary results of this new series of experiments for the period January 1949 to May 1949 were presented previously (2). An account of the study over the entire 2½-year period, January 1949 to July 1951, is presented here.

PROCEDURES

Experimental Plant.—The laboratory tank layout is shown on plate 1 and sketches of experimental septic tanks involved are shown in the appendix, plates 45 to 48. Pertinent features of each tank are given in table 1. Under "Type" the figure indicates the number of compartments and the letter, the shape, whether round-vertical or rectangular.

Seed Sludge.—Tanks 7A, 9A, and 19 were started with "seed" sludge amounting to 10 percent by volume distributed equally among compartments. Operation of tanks 3 and 4, idle during the 6-month suspension of activities, was resumed January 1949 with holdover sludge accumulations of 30 and 34 cubic feet, respectively.

TABLE 1.—Description of septic tanks

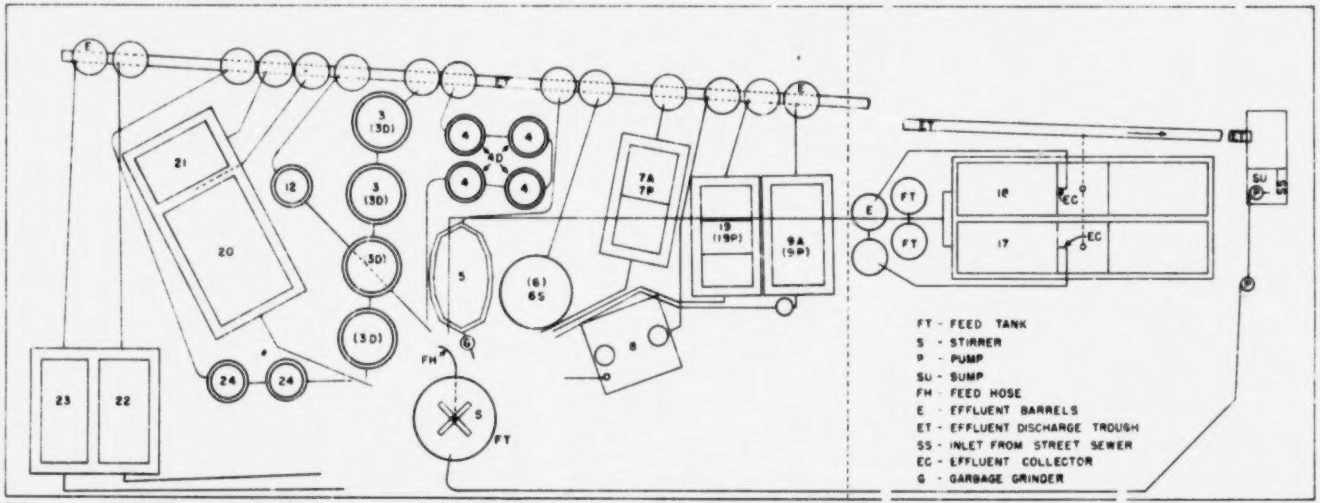
Tank	Total liquid capacity	Width	Total length	Liquid depth	Type
	Gallons	*Feet*	*Feet*	*Feet*	
3	553	3.0 (diameter)		5. 2	2–OV
4	673	2.0 (diameter)		7. 1	4–OV
7A	524	3. 0	6. 0	4. 0	2–R
9A	539	3. 0	6. 0	4. 0	1–R
19	509	3. 0	6. 0	4. 0	3–R

Sludge Additions.—During the course of the experiment sludge obtained from field septic tanks was added periodically to accelerate accumulation so that performance at different sludge levels could be observed, and maximum sludge storage capacity of each tank determined. Quantity and solid content of sludge for each addition is shown in table 2.

TABLE 2.—Sludge additions

Tank	Date	Quantity	T. S.	Volatile
		Gallons	*Percent*	*Percent*
7A, 9A, 19	January 1949	50	7. 8	44. 2
Do	February 1949	75	2. 7	44. 8
3, 4	July 1949	38	8. 6	42. 8
7A, 9A, 19	do	75	8. 6	42. 8
3, 4	December 1949	38	4. 6	53. 5
7A, 9A, 19	do	75	4. 6	53. 5
3, 4	February 1950	38	4. 3	41. 2
7A, 9A, 19	do	75	4. 3	41. 2
All	March 1950	38	7. 5	70. 3
Do	May 1950	38	7. 0	36. 2
Do	June 1950	38	6. 8	83. 5
Do	September 1950	38	9. 6	53. 2
Do	October 1950	38	6. 8	67. 2

Feeding, Sampling, Sludge Measurement.—Each tank received a total of 250 gallons of raw sewage daily in 8 feeds. Displaced effluents were sampled separately. Feeding, sampling and



FT - FEED TANK
S - STIRRER
P - PUMP
SU - SUMP
FH - FEED HOSE
E - EFFLUENT BARRELS
ET - EFFLUENT DISCHARGE TROUGH
SS - INLET FROM STREET SEWER
EC - EFFLUENT COLLECTOR
G - GARBAGE GRINDER

TANK	DESCRIPTION	VOLUME
3	2-36" ϕ STACKS-SERIES	553
3D	4-36" ϕ STACKS-SERIES	500
4	4-24" ϕ STACKS-SERIES	673
4D	4-24" ϕ STACKS-SERIES	500
5	PRECAST OVAL	523
6	VERTICAL CYLINDRICAL	455
6S	VERTICAL CYLINDRICAL	455

TANK	DESCRIPTION	VOLUME
7A	2 COMP. RECT.	524
7P	2 COMP. RECT.	524
8	HORIZONTAL CYLINDRICAL	492
9A	JOINT COMMITTEE-RECT	539
9P	2 COMP. RECT.	539
12	1-24" ϕ STACK	123
17	JOINT COMMITTEE-RECT	539
18	JOINT COMMITTEE-RECT	539

TANK	DESCRIPTION	VOLUME
19	3 COMP. RECT.	509
19P	3 COMP. RECT.	509
20	JOINT COMMITTEE-RECT	500
21	JOINT COMMITTEE-RECT	500
22	JOINT COMMITTEE-RECT	500
23	JOINT COMMITTEE-RECT	500
24	2-24" ϕ STACK SERIES	468

PLATE I

HHFA — USPHS
HOUSEHOLD SEWAGE DISPOSAL PROJECT

EXPERIMENTAL UNIT LAYOUT

SCALE: 1" = 4'
JULY, 1953

sludge measuring procedures were those described in a previous report (1).

RESULTS

Principal criteria by which performance is judged are removal of suspended solids, and ability to retain sludge.

Suspended Solids Removal Efficiency.—Table 3 summarizes removal of suspended solids during the 2-year period, January 1949 to January 1951. No allowance has been made for solids added or lost during periodic sludge additions shown in table 2.

During the 2-year period covered by table 3, each tank received a total of approximately 151,750 gallons of raw sewage averaging 399 p. p. m. suspended solids.

Individual weekly differences in amount of suspended solids in each of the effluents were statistically examined. These tests revealed that there was a significant difference in suspended solids removal, and that the five tanks performed at three levels. The highest level was obtained by tank 4 with an average removal of 77 percent; next were tanks 7A and 3 at approximately 69 percent; and last, tanks 9A and 19 at approximately 61 percent.

TABLE 3.—Suspended solids in effluent and percent removal, multicompartment tanks, January 1949 to January 1951

Item	Unit	Tank No.				
		3	4	7A	9A	19
Type of tank		2–OV	4–OV	2–R	1–R	3–R
Suspended solids, effluent	P. p. m.	128	90	121	152	157
Average removal [1]	Percent	68	77	70	62	60
Median removal [2]	Percent	69	80	71	65	63

[1] Average weighted for gallons of sewage.

[2] Median value of individual weekly suspended solids removals.

Simultaneous plots of suspended solids removal efficiencies and amount of sludge accumulated for each tank, largely from the intermittent sludge additions, are given in plates 2 to 6. The plates show that all five tanks reached their sludge storage capacities during early summer of 1951. Suspended solids removal efficiencies ranged between 39 and 25 percent for the period, January to July 1951; as against 60 to 77 percent for the 2-year period prior to January 1951. No significant difference in efficiency among any of the tanks could be statistically demonstrated for the final 6 months, further indicating a change in behavior.

Sludge Accumulation.—Sludge measurements, using apparatus described previously (1), were made at the start of each week of operation.

Plates 2 to 6, inclusive, show the relationship between sludge volume and efficiency as measured by removal of suspended solids. Frequent artificial additions of sludge, undoubtedly, had an adverse effect on efficiency. However, all tanks gave acceptable performance while sludge volume built up to a high in January 1951. Each tank discharged some sludge during the period of failure in early summer of 1951.

Sludge accumulations at 6-month intervals have been chosen to illustrate comparative sludge storage performances. These data are shown in table 4. July 1950 probably represents maximum volume for acceptable year-round suspended solids removal efficiency. By January 1951, sludge exceeds the permissible volumes, but due to slow winter digestion, no deterioration of effluent quality is evident. Figures for June 1951 indicate final sludge volumes.

TABLE 4.—Volume of sludge retained in tank

Month	Total sludge accumulated (cubic feet) [1]				
	3	4	7A	9A	19
July 1950	48	61	39	30	31
January 1951	50	64	41	34	32
June 1951	46	62	38	33	28

[1] From start of experiment through month indicated.

In evaluating ability of the tanks to retain sludge, differences in liquid capacity must be considered. Tank 3 contains approximately 4, and tank 4 approximately 20 cubic feet more capacity than the average of the other 3 tanks. If sludge volumes are corrected by these amounts, tanks 3,

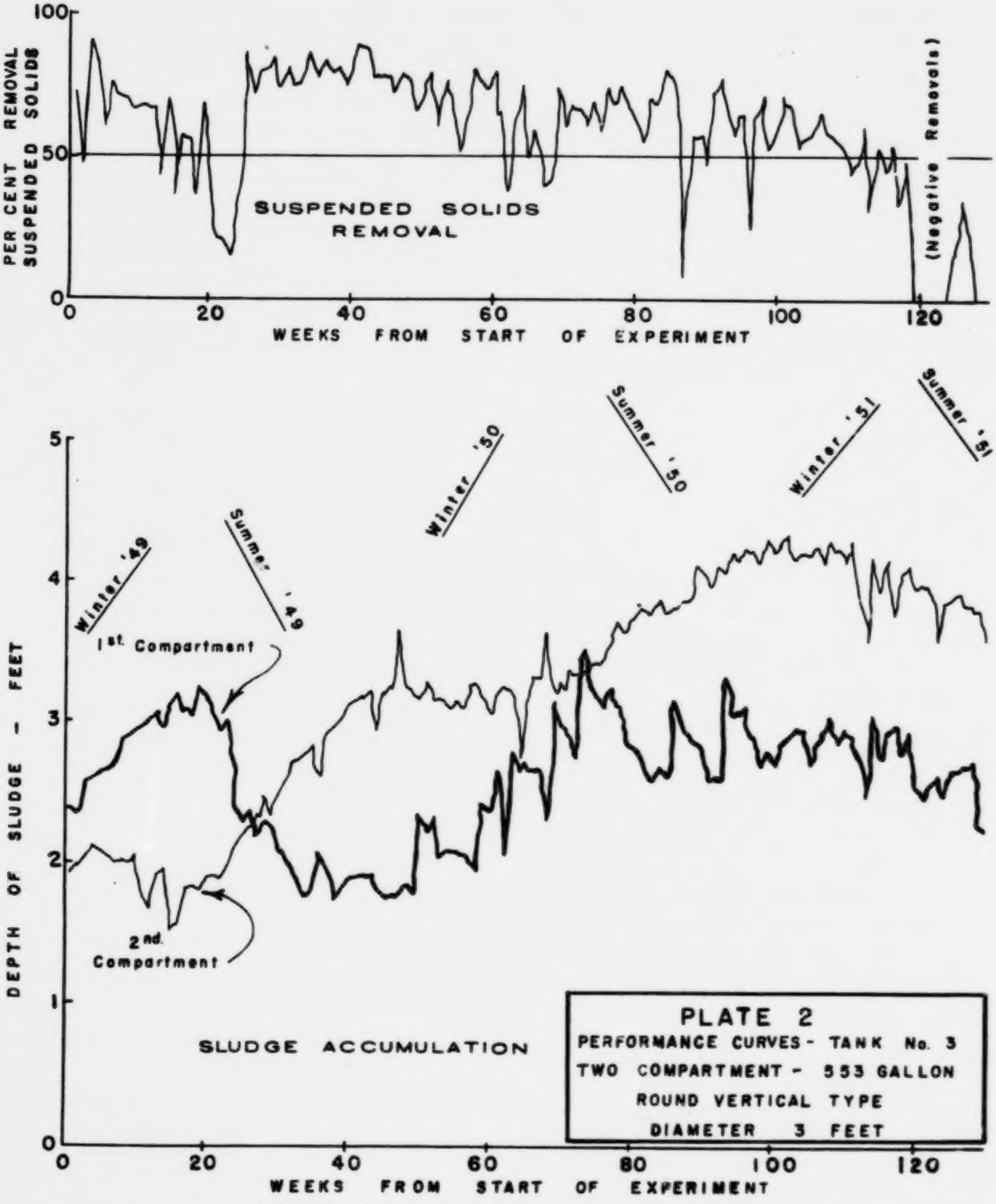


PLATE 2

PERFORMANCE CURVES - TANK No. 3

TWO COMPARTMENT - 553 GALLON

ROUND VERTICAL TYPE

DIAMETER 3 FEET

EXPERIMENT STARTED JANUARY 17, 1949

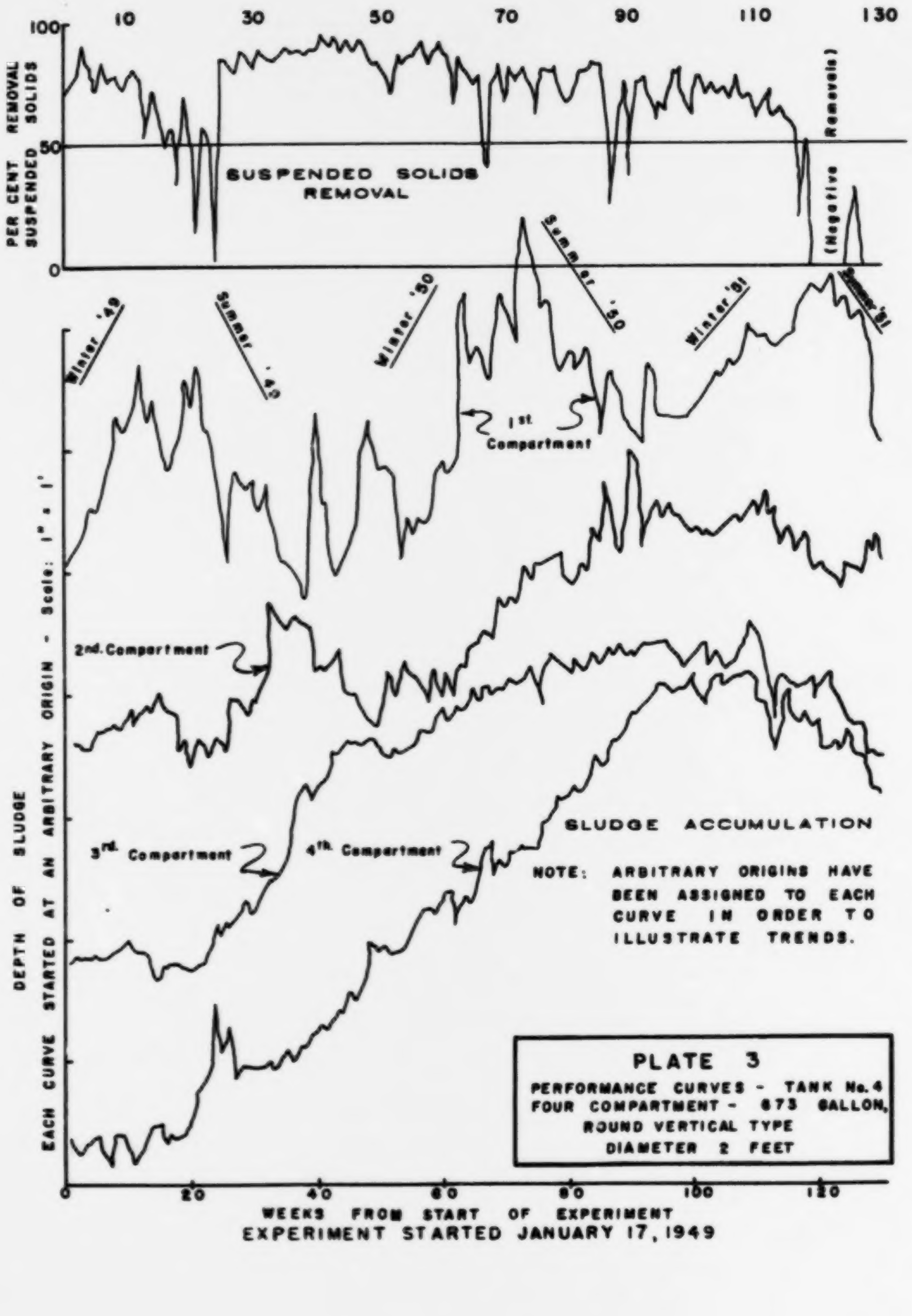


PLATE 3

PERFORMANCE CURVES - TANK No. 4
FOUR COMPARTMENT - 673 GALLON,
ROUND VERTICAL TYPE
DIAMETER 2 FEET

PLATE 4

PERFORMANCE CURVES - TANK No. 7A
TWO COMPARTMENT - 500 GALLON
JOINT COMMITTEE TYPE SHELL

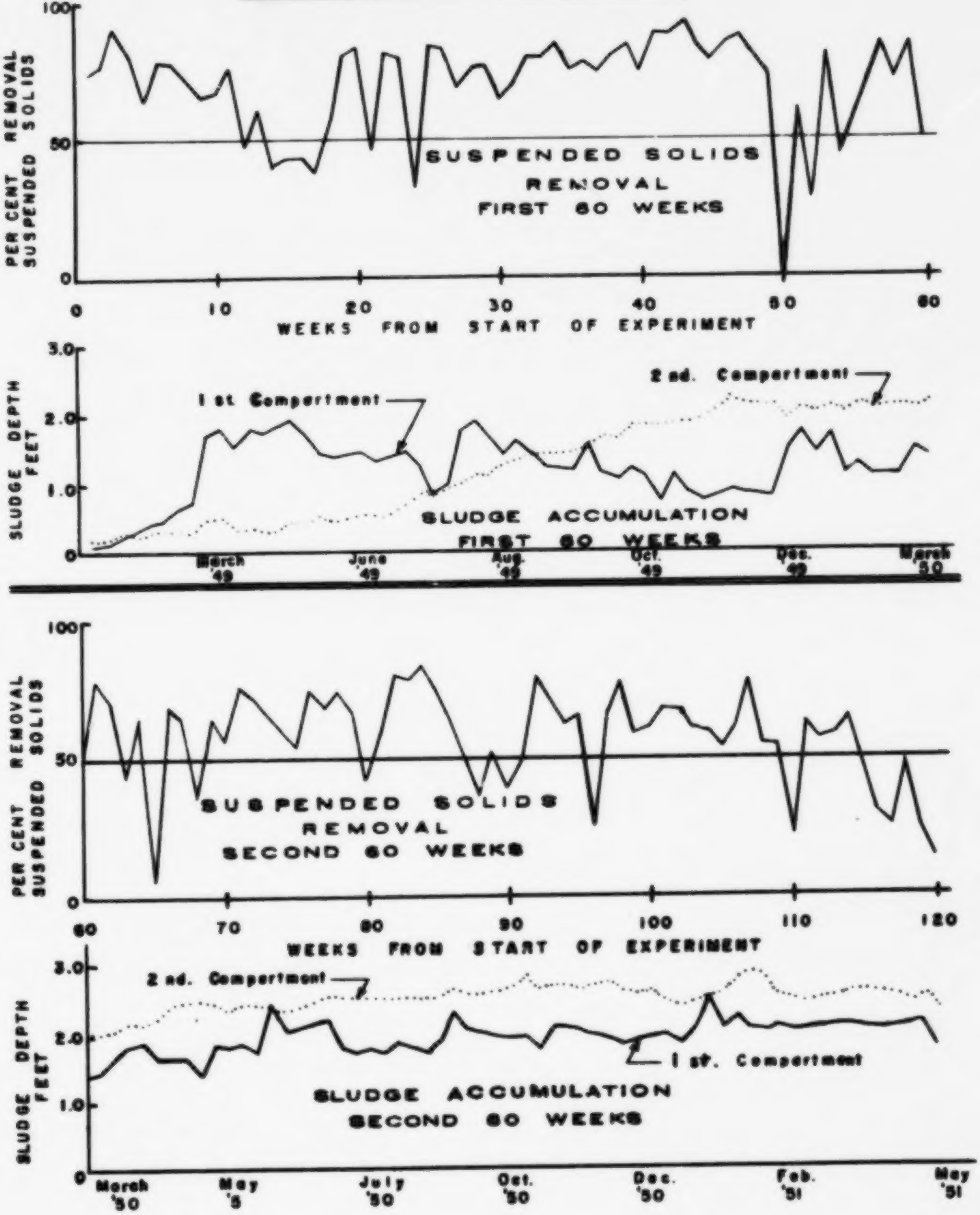


PLATE 5

PERFORMANCE CURVES - TANK No. 9A
SINGLE COMPARTMENT - 500 GALLON
JOINT COMMITTEE TYPE

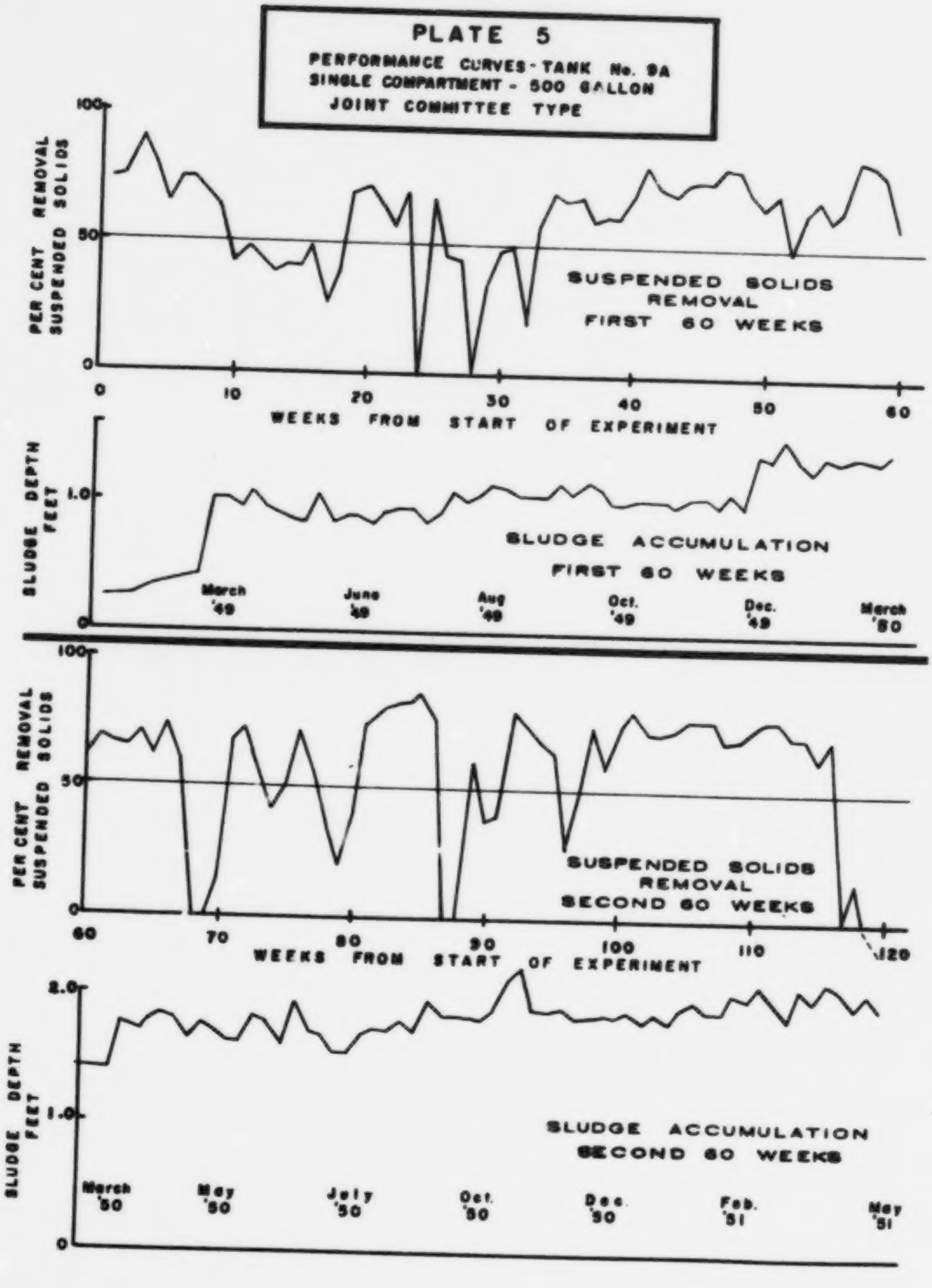
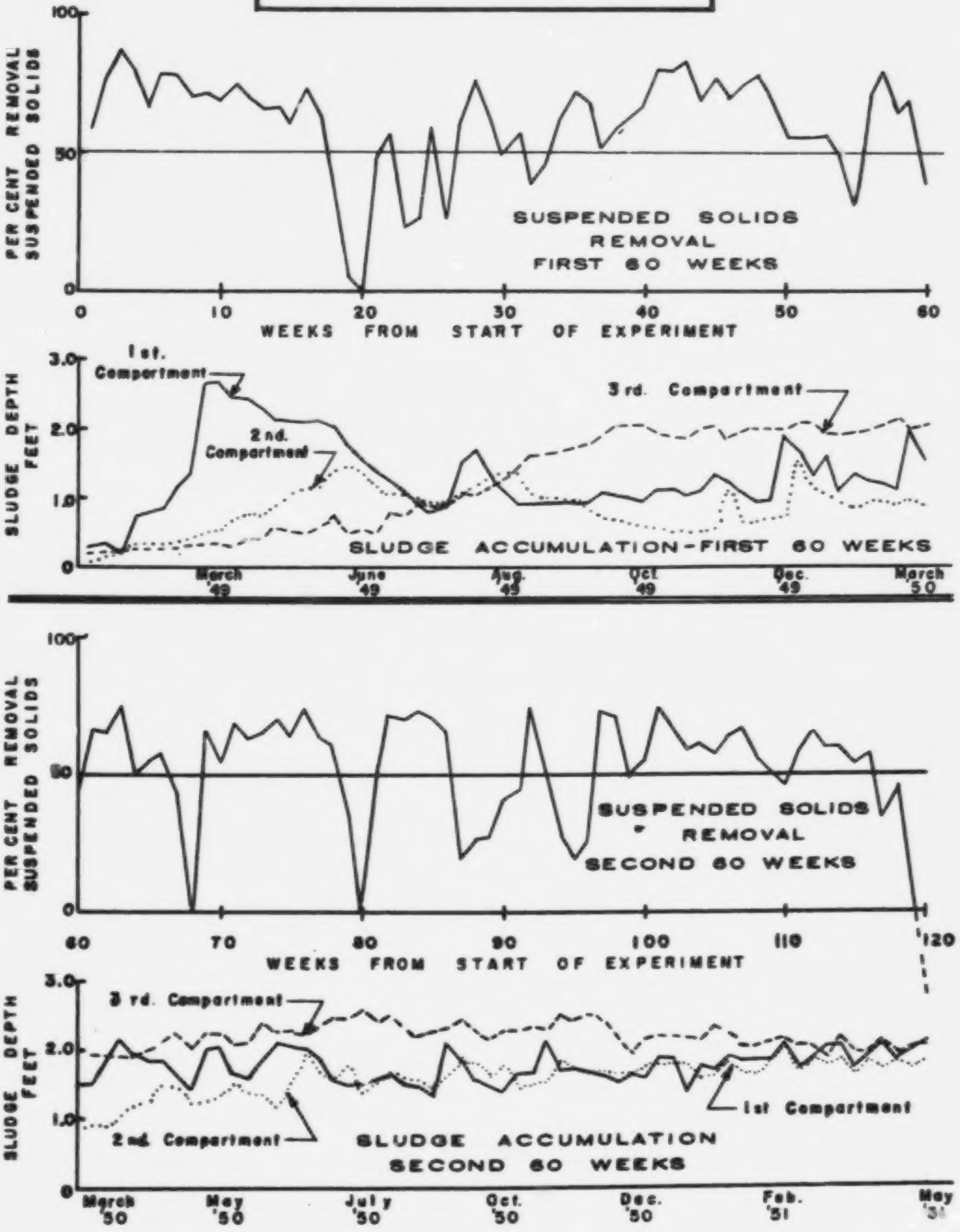


PLATE 6

PERFORMANCE CURVES - TANK No. 19
THREE COMPARTMENT - 500 GALLON
JOINT COMMITTEE TYPE SHELL



4, and 7A are about equal with roughly 40 cubic feet, while tanks 9A and 19 stored approximately 30 cubic feet of sludge. Thus, in sludge storage as well as suspended solids removal efficiency, both of the 2-compartment tanks and the 4-compartment tank performed at a higher lever than either the single-compartment (control) or the 3-compartment tank.

Clear Space.—On page 29, "Sludge clear space" is defined as the distance between bottom of outlet device and top of sludge. Minimum sludge clear space occurs when the tank has reached its capacity to retain sludge.

Sludge clear spaces which existed in each of the tanks during the 3 months previously discussed are shown in table 5.

TABLE 5.—Sludge clear space—multicompartment tanks

Month	Tank		Sludge clear space (feet)				
	No.	Type	1st compartment	2d compartment	3d compartment	4th compartment	Tank average
July 1950	3	2–OV	1.27	0.76	----------	----------	1.01
Do	4	4–OV	1.88	1.73	0.63	1.71	1.49
Do	7A	2–R	.75	.21	----------	----------	.48
Do	9A	1–R	1.01	----------	----------	----------	1.01
Do	19	3–R	1.14	1.12	.27	----------	.85
January 1951	3	2–OV	1.52	.18	----------	----------	.85
Do	4	4–OV	2.17	1.44	.56	.74	1.23
Do	7A	2–R	.56	.13	----------	----------	.34
Do	9A	1–R	.81	----------	----------	----------	.81
Do	19	3–R	.96	.98	.48	----------	.81
June 1951	3	2–OV	1.78	.56	----------	----------	1.17
Do	4	4–OV	1.60	1.77	.94	1.20	1.38
Do	7A	2–R	.71	.31	----------	----------	.51
Do	9A	1–R	.86	----------	----------	----------	.86
Do	19	3–R	1.21	1.12	.90	----------	1.08

Average sludge clear space is somewhat less than that which would develop in single-compartment tanks of equal surface area. Sludge clear space tends to be greater in the first compartment than in the last compartment.

Character of Sludge.—An investigation was made to determine any difference in characteristics existing between sludge found in the first compartment and that found in subsequent compartments. Samples were taken from the top layer of sludge in the compartments of tank 4 at various times, as indicated in table 6. The reduction that takes place in percentage volatile matter, as sludge solids move downstream from compartment to compartment, is illustrated. The reduction was computed from the difference in volatile matter associated with a unit weight of ash.

TABLE 6.—Volatile sludge matter—tank 4

Date	Percent volatile solids				Percent reduction volatile sludge solids—first to last compartment
	1st compartment	2d compartment	3d compartment	4th compartment	
Jan. 22, 1951	58.0	------	------	49.5	29
Mar. 5, 1951	60.5	52.4	47.2	47.6	41
Mar. 14, 1951	60.3	48.3	47.7	50.5	33
Apr. 2, 1951	79.6	52.4	46.7	49.4	75

There is no ready explanation for the fact that third compartment sludge had consistently showed slightly lower percentages of volatile matter than that in the fourth compartment.

The percentage of volatile matter in the sludge also decreases from top to bottom in each compartment. Top and bottom sludge samples were taken from tank 19 on February 7, 1951. Bottom sludge solids contained 38.1, 40.0, and 38.1 percent volatile matter for the first, second, and third compartments, respectively. Corresponding top samples contained 61.0, 53.0, and 45.6 percent volatile matter, representing apparent reductions of 60, 41, and 28 percent, respectively.

DISCUSSION OF RESULTS

The two 2-compartment tanks and the 4-compartment tank show an improvement in performance over the single-compartment control tank, both on the basis of suspended solids removal efficiency and the ability to retain digesting sludge. On both counts, the 3-compartment tank was approximately equal to the control tank.

Sludge curves indicate a basic difference in the function of the first as opposed to subsequent compartments (plates 2 to 6). The first compartment accumulated sludge rapidly during the winter, but lost a good proportion of it during the summer. Conversely, the last compartment made its largest gains during the summer when sludge was being lost from the first compartment. The last compartment showed only small gains in accumulation during winter months while the first compartment was carrying the load. Although this behavior is masked somewhat during the second year by frequent additions of sludge, the trend is evident.

The behavior described is a reflection of the influence that temperature exerts on rate of digestion. Subsequent compartments serve as stand-by units to arrest heavy discharge of sludge solids from the first compartment during periods of rapid digestion.

The behavior of a multi-compartment tank of proper capacity and design represents a natural separation of sedimentation and digestion. In septic tanks, all of the sewage, liquid as well as solid, is subjected to rapid anaerobic digestion in the first compartment, so that interference with sedimentation is minimized in subsequent compartments. In some respects, the process is somewhat similar to that of multistage sludge digestors.

Caution must be exercised in comparing the performance of tanks 3 and 4 with that of 7A, 9A, and 19. The study was started with a sizable accumulation of sludge in tanks 3 and 4; while 7A, 9A, and 19 were started with a nominal amount of seed sludge. Differences in capacity must also be considered. Liquid capacity of the first three compartments of tank 4 totaled approximately 500 gallons. The extra capacity of tank 4 can be considered as being contained in the fourth compartment—a premise which leads to an interesting comparison between tanks 4 and 19.

During the winter and spring of 1949, tank 19 registered a suspended solids removal of 73 percent. In fact, at the start of the experiment, the tanks ranked in efficiency in order from the highest to the lowest number of compartments.

Sludge accumulated rapidly in the first compartment during the first winter (pl. 6). With the advent of warm summer weather and rapid digestion, an appreciable bulk of the sludge shifted downstream to the second and third compartments. The action of the first compartment was similar to that of the 123-gallon single-compartment tank 12, discussed in Section B, page 32.

Unlike tank 7A, when sludge solids reached the second compartment of tank 19, they were not held, but continued to shift downstream to the third compartment. It is possible that insufficient capacity was provided in the first compartment to treat the solids properly. As a result, rapid digestion and gasification were still taking place when the solids reached the second compartment, so that both the first and the second compartments probably served as primary digesters, with attendent agitation.

Sludge reached the third compartment in stable condition, as indicated by the shape of the accumulation curve, plate 6. However, by the end of the summer of 1949, the third compartment was full of sludge and the efficiency of the tank depended on the erratic performance of the first two compartments.

Essentially the same pattern developed in tank 4. The first two compartments seemed to function similarly to the first compartment of either tank 3 or 4. Sludge sloughed from the first two compartments to the third. In the case of tank 4, as the third compartment filled with sludge, the rate of accumulation in the fourth compartment increased progressively. By December 1950, the fourth compartment contained 17.6 cubic feet of sludge. Had this been a three-compartment tank similar to tank 19, these solids would have passed out in the effluent, causing a reduction in suspended solids removal efficiency.

Compartment Proportions

PROCEDURES

Experimental Plant.—Rectangular shells 6 feet long and [illegible] feet wide, with a liquid depth of 4 feet, were utilized to provide three 2-compartment tanks. One tank was divided into two equal compartments; one was divided so that two-thirds of its capacity was in the first compartment; and the third tank was provided with one-third of its capacity in the first compartment.

Sketches of experimental tanks involved are shown in the appendix, plates 46 and 48. Tank reference numbers and capacity distribution are given in table 7.

TABLE 7.—**Distribution of capacity**

Tank No.	Capacity (gallons)	
	1st compartment	2d compartment
7P	262	262
9P	351	173
19P	173	351

Sludge Additions.—Fifty gallons of seed sludge were added to the first compartment of each tank at the start of the experiment in August 1951. In order to accelerate sludge accumulation, another 55 gallons of well-digested septic tank sludge were added to each tank in December 1951.

Feeding and Sampling.—Prior to June 1952, feeding and sampling procedures were identical with those described in a previous report (1). After that date, weekly laboratory operations were reduced to five 8-hour days. Total quantity of sewage applied daily to each tank was kept at 250 gallons. Eight daily feeds were made in the quantities and following the schedule shown in table 8. No change in the pattern of behavior as reflected by removal of suspended solids could be detected following shortening of the interval between feeds. Even if differences had developed, it is improbable that a change would affect one tank more severely than the other.

TABLE 8.—**Modified feed schedule commencing June 1952**

Feed No.	Time	Raw sewage (gallons)	Feed No.	Time	Raw sewage (gallons)
1	9 a. m.	32. 5	5	1 p. m.	35. 0
2	10 a. m.	30. 0	6	2 p. m.	37. 5
3	11 a. m.	25. 0	7	3 p. m.	32. 5
4	12 noon	32. 5	8	4 p. m.	25. 0

No feeds on Saturday or Sunday.

RESULTS AND DISCUSSION

Suspended solids removal efficiency, based on raw sewage feeds, and the accumulation of digesting sludge were used as principal parameters of performance.

Suspended Solids.—Approximately 107,765 gallons of raw sewage averaging 520 p. p. m. suspended solids were added to each tank during the investigation. Table 9 summarizes removal of suspended solids for the entire 94 weeks.

TABLE 9.—**Suspended solids in effluent and percent removal–compartment proportions, Aug. 5, 1951, to May 15, 1953.**

Item	Unit	Tank No.		
		7P	9P	19P
Suspended solids (effluent)	P. p. m.	172	167	227
Average removal[1] suspended solids.	Percent	67	68	56

[1] Average weighted for gallons of sewage fed.

From table 9, it is seen that the suspended solids removal efficiency of tanks 7P and 9P was 67 and 68 percent, respectively. This performance is equivalent to that of the two equal-compartment tanks reported in section A, page 13. Tank 19P, with an efficiency of 56 percent, gave performance roughly equivalent to that of a single-compartment tank.

Sludge Accumulation.—Sludge sounding rods of the type shown in a previous report (1) were used to measure sludge accumulation at the start of each week.

The pattern of behavior without the disturbing influence of frequent sludge additions was desired; therefore, maximum sludge storage capacity was not obtained during time allotted for the experiment. However, final sludge accumulations substantiate suspended solids removal performance. An average of the last 5 soundings in each tank reveals approximate accumulations of 28.5 cubic feet in both 7P and 9P, compared with 23.0 cubic feet in 19P.

Intercompartment Samples.—During winter 1951 and spring 1952, a series of samples was taken from individual compartments to determine the difference in quality of supernatant liquor in the first compartment, as compared with that in the second compartment. Samples were obtained midway between liquid surface and sludge blanket. Comparison was made on basis of suspended solids and percent volatile matter in suspended solids. Results are shown in table 10.

In all of the tanks, smaller concentrations of supernatant liquor suspended solids were found in second compartments than in first compartments. In tanks 7P and 9P, supernatant liquor suspended solids from second compartments generally contained a higher proportion of volatile matter than those from the first compartment. This trend was reversed in tank 19P.

TABLE 10.—Suspended solids contained in supernatant liquors of first compartment compared with those in second compartment

Date	Tank No.											
	7P				9P				19P			
	1st compartment		2d compartment		1st compartment		2d compartment		1st compartment		2d compartment	
	Suspended solids p. p. m.	Percent volatile	Suspended solids p. p. m.	Percent volatile	Suspended solids p. p. m.	Percent volatile	Suspended solids p. p. m.	Percent volatile	Suspended solids p. p. m.	Percent volatile	Suspended solids p. p. m.	Percent volatile
Oct. 9, 1951	266	80	100	88	326	69	96	88	476	74	172	73
Dec. 10, 1951	298	54	130	66								
Dec. 20, 1951					88	68	84	76	140	80	106	72
Feb. 12, 1952	132	88	104	100	154	83	102	92	216	89	132	89
Apr. 7, 1952	210	67	92	83	166	58	82	78	118	69	106	66
May 7, 1952	266	68	324	67	248	56	378	61	292	73	230	72
June 19, 1952	372	32	132	68	260	67	140	73	224	70	266	63
July 21, 1952	140	57	124	55	364	53	88	57	120	53	118	58
Average	240	60	144	71	229	61	139	71	217	73	161	70

Liquid Depth in Multicompartment Tanks

INTRODUCTION

Several opportunities arose during the project to observe behavior of multicompartment tanks at various liquid depths, some incidental to study of other factors. Two experiments undertaken to provide additional information on the depth factor are reported in detail here. These were conducted at different times, as tanks became available upon completion of other operations, and are reported separately. The first concerns a multicompartment tank of 120 inches liquid depth; the second, 2 multicompartment tanks of 28½ and 62 inches liquid depths, respectively.

Experiments presented in a previous report (1) indicated that some multicompartment tanks of simple design produced suspended solids removals of approximately 80 percent, as against 59 to 65 percent for single-compartment tanks of the same capacity. Also, the performance of two-compartment tanks 7A and 3, reported earlier in this section, indicated that with liquid depths of 48 and 63 inches there was little if any difference in suspended solids removal between the two, in a 2-year run (68 and 70 percent, respectively).

120-Inch Liquid Depth

INTRODUCTION

Study of a two-compartment tank, made up of 24-inch diameter vertical cylinders, was undertaken at the request of the co-sponsor of the project, in connection with interest in installation economies in use of pipe and bored hole excavation. At 500 gallons nominal capacity, such tank would necessarily be very deep, and the performance of such a tank, therefore, became of interest.

PROCEDURES

Experimental Plant.—On January 15, 1950, the deep, 2-compartment tank was put into operation. Identified as tank 24, it consisted of vertical cylindrical sections 2 feet in diameter and 2 feet long, stacked one on top of the other and joined with a sand-cement grout. As constructed, liquid depth in the first compartment was 10.0 feet, and in the second, 9.8 feet, providing total liquid capacity of 468 gallons. A sketch of tank 24 is shown in the appendix, plate 49, and the layout on plate 1.

Sludge Additions.—Tank 24 was started with 50 gallons of "seed" sludge divided between the two compartments. During the course of the experiment, sludge obtained from field septic tanks was added periodically to accelerate sludge accumulation so that performance at higher sludge levels could be observed and maximum sludge storage capacity could be determined. Quantity and solids content of sludge for each addition are given in table 11.

TABLE 11.—Sludge additions, tank 24

Date	Quantity	Total solids	Total volatile solids
	Gallons	*Percent*	*Percent*
Dec. 28, 1949	50	4. 57	53. 5
Feb. 28, 1950	75	4. 30	41. 2
Mar. 29, 1950	37. 5	7. 52	70. 3
May 10, 1950	50	6. 98	36. 2
Oct. 27, 1950	37. 5	6. 82	67. 2
Jan. 29, 1951	50	8. 30	61. 0
Apr. 13, 1951	60	8. 00	53. 0
Apr. 24, 1951	55	8. 17	58. 3

Feeding and Sampling.—Tank 24 received a total of 250 gallons of raw sewage daily in eight separate feeds. Displaced effluent was collected, a sample was taken, and the remainder wasted at each feed. The feeding, sampling, and sludge measuring procedures used in this experiment are the same as those described previously (1).

RESULTS

Suspended Solids Removal.—Behavior of the deep 2-compartment tank was observed for a period of 77 weeks. During that period, approximately 108,680 gallons of raw sewage averaging 396 p. p. m. suspended solids were added to the tank.

Simultaneous plots of suspended solids removal efficiency and of sludge accumulation are shown on plate 7. A seasonal break in performance occurred during the early summer of 1950. Efficiency in suspended solids removal recovered in July and, except for a temporary upset, remained relatively high during the balance of 1950. After a sludge addition on January 29, 1951, the tank showed signs of declining efficiency. Failure occurred after heavy sludge additions during April 1951.

During the 65-week period, January 15, 1950, to April 15, 1951, prior to failure, the tank removed 60 percent of the suspended solids.

Sludge Accumulation.—Sludge measurements taken during the five-week period, December 26, 1950, to January 29, 1951, when removal of suspended solids was good, averaged 23 cubic feet. Similar measurements taken during the 5-week period prior to failure, March 5, 1951, to April 9, 1951, indicated an average of 29.4 cubic feet.

DISCUSSION

Tank 24 removed 60 percent of the suspended solids for a 65-week period, prior to failure. This performance compares equally with that which could be expected of a single-compartment tank (tank 9A, table 3, p. 13). It is below the performances obtained in two-compartment tanks of less radical proportions (tanks 3 and 7A, table 3, p. 13).

Referring to plate 7, the pattern of sludge accumulation in tank 24 differs from that expected of a 500-gallon, 2-equal-compartment tank. The first and second compartments show identical trends in sludge accumulation. This pattern is in contrast with that for tank 3, plate 2, page 14, which may be used as an example of a 2-compartment tank operating at a high level of suspended solids removal efficiency.

One inference which might be drawn from these curves is that the confined surface area of the deeper tank was responsible for a greater degree of disturbance caused by digesting sludge. This disturbance may have reduced the efficiency of the first compartment enough to permit transfer of relatively raw solids to the second compartment. Thus, rapid digestion and gasification would also take place in the second compartment. Rapid digestion throughout the length of the tank is the type of behavior attributed to single-compartment tanks, and probably explains the close agreement of suspended solids removal in tank 24 with that of single-compartment tanks.

Good performance was observed with approximately 23 cubic feet of sludge in the tank. Just prior to failure the tank held approximately 29.4 cubic feet of sludge. These accumulations represent average sludge clear spaces of approximately 3.0 and 2.0 feet, respectively. A safe minimum clear space would probably fall somewhere between these two values.

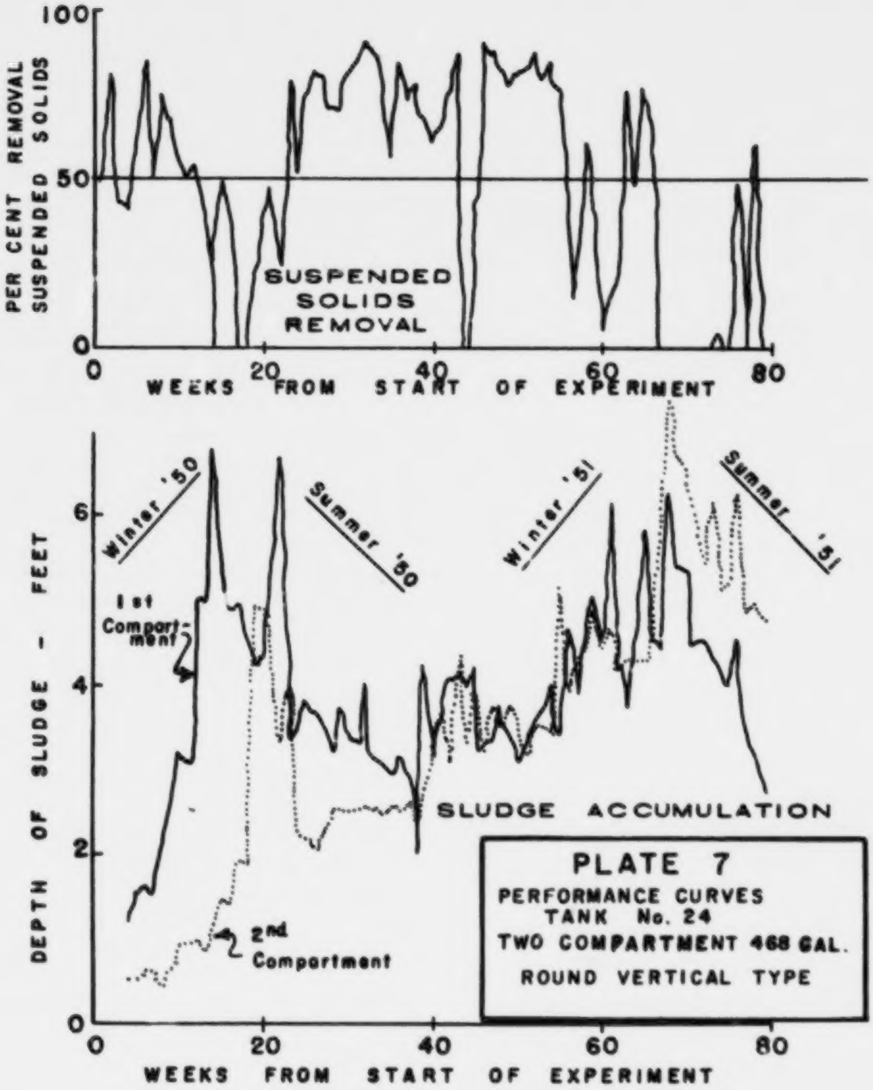


PLATE 7
PERFORMANCE CURVES
TANK No. 24
TWO COMPARTMENT 468 GAL.
ROUND VERTICAL TYPE

EXPERIMENT STARTED JANUARY 15, 1950

28½- and 62-Inch Liquid Depths

PROCEDURES

Experimental Plant.—The effect of liquid depth on performance of multicompartment tanks was investigated in two 4-compartment vertical cylindrical tanks, representing, for practical purposes, 2 extremes in depth. The study was conducted over a period of 53 weeks, July 1951 to August 1952. Sketches of the tanks involved are shown in appendix A, plate 50, and their laboratory layout is shown on plate 1. Pertinent features of the tanks are given in table 12.

TABLE 12.—Description of multicompartment depth tanks

Tank No.	Type	Total liquid capacity	Diameter each compartment	Liquid depth
		Gallons	*Feet*	*Inches*
3D	4-OV	500	3	28.5
4D	4-OV	500	2	62.0

Sludge Additions.—Tanks 3D and 4D were started in July 1951, with 50 gallons of seed sludge in the first compartment of each tank. Fifty gallons of well-digested septic tank sludge were added to each tank in December 1951.

Feeding and Sampling.—Feeding and sampling procedures were identical with those outlined in section A, page 21.

RESULTS

Efficiency in the removal of suspended solids and the ability to retain digesting sludge were used as parameters of performance.

Suspended Solids.—During the first 39 weeks, July 1951 to April 1952, the shallow tank removed 79 percent of the raw sewage suspended solids, as compared with 75 percent for the deeper tank. However, during the last 14 weeks, May to August 1952, performance of both tanks dropped off. The break was particularly severe in tank 4D, the deeper tank, which showed negative suspended solids removal of minus 22 percent. For the same period, shallower tank 3D removed 65 percent of the suspended solids.

For the overall 53-week period, July 1951 to August 1952, suspended solids removal efficiencies were 77 percent for the shallower tank, as compared with 58 percent for the deeper tank.

Sludge Accumulation.—At the end of 39 weeks, there were approximately 27 and 30 cubic feet of sludge in the shallower and deeper tanks, respectively. When the experiment was concluded, the shallower tank contained 23 cubic feet of sludge, compared with 19 cubic feet in the deeper tank.

DISCUSSION

During the initial phase of the experiment, significance of the difference in suspended solids removal efficiency is doubtful. However, during the final 14 weeks, superior performance of the shallower tank is unquestioned.

The break in suspended solids removal efficiency came in conjunction with rapidly rising effluent temperatures. Average effluent temperatures rose from 61.9° F. for the week May 12 to 18, 1952; to 81.3° F. for the week June 30 to July 6, 1952. Effluent temperature averaged 84.2° F. for the day, June 30, 1952. Maximum average weekly temperatures were 78.0° F. in 1951, and 75.2° F. in 1950.

The rapid rise in effluent temperatures caught both tanks with a large volume of sludge which had accumulated during the winter. Magnitude of this accumulation is shown in table 13.

TABLE 13.—Sludge accumulation—compartment depth

Date	Sludge volume (cubic feet)	
	Tank 3D (28.5 inches deep)	Tank 4D (62 inches deep)
Sept. 8, 1951	9. 2	13. 2
May 5, 1952	29. 7	30. 9
Aug. 1, 1952	22. 8	19. 4

Reduction of sludge volume which took place in tank 3D probably resulted from digestion and compaction, in that suspended solids removals were high. On the other hand, as indicated by negative suspended solids removal efficiency, previously accumulated sludge solids were discharged from tank 4D during spring and summer, 1952.

Poor performance in this period was not limited to tank 4D. Three multicompartment tanks under observation at the same time in the compartment proportion investigation, section A, page 20, registered negative efficiencies also, ranging from minus 2 percent for tank 9P to minus 37 percent for tank 19P.

Further Studies on Single-Compartment Tanks

Liquid Depth

INTRODUCTION

The effect of liquid depth on performance became of particular interest where prefabricated tanks with depths less than the commonly recommended 4-foot minimum were offered, or where environmental conditions were such as to make a shallow tank installation seem attractive. During the first phase of these studies, 5 varishaped, single-compartment, 500-gallon septic tanks gave equal performance. Liquid depths did not vary substantially from 4 feet.

PROCEDURES

Experimental Plant.—To determine the relationship between liquid depth and performance, 4 septic tanks of 500-gallon capacity, but with different liquid depths, were operated simultaneously, with like feeds. Sketches of experimental septic tanks involved are shown in the appendix on plate 51, and their laboratory layout is shown on plate 1. Pertinent tank dimensions are tabulated in table 14.

TABLE 14.—Tank dimensions

Tank No.	Liquid depth	Length	Width	Penetration (inches)[1]	
				Inlet	Outlet
	Inches	*Feet*	*Feet*		
20	28.5	7.50	3.75	6	6.00
21	64.0	5.00	2.50	6	18.75
22	48.0	5.83	2.92	6	13.00
23	36.0	6.67	3.33	6	8.62

[1] Distance from liquid surface to bottom of tee.

Feeding and Sampling.—Each tank received a total of 250 gallons of raw sewage daily in 8 separate feeds. Feeding, sampling, and sludge measuring procedures described in a previous report (1) were followed.

FIRST TRIAL

Sludge Additions.—Tanks 20, 21, 22, and 23 were started November 7, 1949, following addition of 50 gallons of ripe seed sludge to each tank. Additions of well-digested sludge were made from time to time to accelerate sludge accumulation, so that the maximum sludge storage capacity of each tank could be determined. Data on sludge used for each addition are given in table 15.

TABLE 15.—Sludge additions

Date	Quantity	Total solids	Total volatile solids
	Gallons	*Percent*	*Percent*
Nov. 3, 1949	[1] 50	8.55	42.8
Dec. 29, 1949	75	4.57	53.5
Feb. 28, 1950	50	4.30	41.2
Mar. 29, 1950	40	7.52	70.3

[1] Seed sludge.

Results.—Performances were compared on suspended solids removal efficiency and ability to store digesting sludge. Prior to December 12, 1949, good suspended solids removals were obtained with all four tanks. At that point, the penetrations of inlet and outlet tees were adjusted to conform with latest sludge and scum accumulation equations derived from field data. Inlet and outlet tee penetrations, originally set at 35.5 percent of liquid depth, were altered to the dimensions shown in table 14. After alterations were made, and an additional 75 gallons of sludge were added to each tank, feeds were resumed on January 2, 1950.

Following this interruption, persistent erratic behavior developed in the 48-inch-deep tank. Probably as a result of sludge additions, shown in table 15, efficiency dropped in all four tanks, but the disturbance was especially severe in the 48-inch liquid depth tank. A side experiment indicated that the change in outlet penetration was probably not the cause of the drop in efficiency. Efficiencies for the 26-week period, November 7, 1949, to May 7, 1950, are tabulated in table 16.

TABLE 16.—Percent removal of suspended solids—first trial

Period	Liquid depth (inches)			
	28.5	64	48	36
Nov. 7, 1949, to Dec. 29, 1949	75	78	72	77
Nov. 7, 1949, to May 7, 1950	60	64	30	56

Prior to addition of sludge in December 1949, good results were obtained with all four tanks. No practical significance can be attached to the differences in performance for that period.

After that time, approximately equal results were obtained from the 28.5-, 36-, and 64-inch deep tanks. The deepest tank showed more stable performance following each sludge addition, resulting in an apparent advantage for the overall period. However, large additions of sludge are so foreign to normal septic tank operation that no practical advantage is demonstrated.

The low performance obtained with 48-inch liquid depth, tank 22, is inconsistent with previous better results from tanks of this type and liquid depth (tank 7 in previous report (1), and tank 9A, this report, sec. A, p. 13). No explanation could be found for its showing, except perhaps the frequent heavy additions of sludge.

SECOND TRIAL

Sludge.—Tanks were emptied and restarted in May 1950. Sludge from 48-inch liquid depth, tank 22, was wasted. Sludge from the remaining three tanks was pooled, mixed, and redistributed among all 4 tanks as seed sludge. Feeds were resumed on May 15, 1950, with 82 gallons of sludge in each tank.

Results.—For four weeks after the restart, poor results were obtained from the 48- and 64-inch-deep tanks. By June 11, 1950, these tanks recovered, and all 4 tanks performed exceptionally well until sludge was added on September 8, 1950. Removals of suspended solids for the first 16-week period at low sludge levels were 74, 76, 82, and 81 percent for the 64-, 48-, 36-, and 28.5-inch tanks, respectively. These efficiencies neglect the first 4 weeks of poor performance for the 64- and 48-inch tanks. If those results are included, efficiencies are 73 and 61 percent, respectively.

INVESTIGATION OF MAXIMUM SLUDGE STORAGE CAPACITY

A program of accelerated sludge additions was undertaken to determine maximum sludge storage capacity for each tank. Quantity and solid content of sludge used for each addition is shown in table 17.

TABLE 17.—Sludge additions

Tank No.	Date	Quantity	Total solids	Total volatile solids
		Gallons	*Percent*	*Percent*
All	May 12, 1950	82	4.87	70.7
	Sept. 8, 1950	50	9.58	53.2
	Sept. 22, 1950	50	6.59	71.3
	Nov. 20, 1950	100	4.04	51.8
	Feb. 19, 1951	47	5.32	57.5
	Apr. 13, 1951	40	8.00	53.0
21	Apr. 24, 1951	40	8.17	58.3
22	do	80	8.17	58.3
23	do	65	8.17	58.3
24	do	55	8.17	58.3
All	Aug. 24, 1951	55	13.76	40.6
20	Oct. 15, 1951	40	15.49	40.4

It was planned to raise the sludge level in each tank by gradual increments until maximum sludge storage capacity was reached, as indicated by suspended solids removal efficiency curves. However, sludge additions produced disturbances followed by poor quality effluents, so that removal of suspended solids became an unreliable parameter.

Simultaneous plots of suspended solids removal efficiency and depth of sludge in the tanks are shown on plate 8. Sludge curves illustrate that maximum sludge depth was developed in each of the tanks. The results are summarized in table 18.

TABLE 18.—Limiting sludge depths

Tank No.	Depth	Sludge depth at which—	
		Efficiency curve broke	Accumulation curve leveled off
	Inches	*Feet*	*Feet*
20	28.5	1.0	1.5
21	64	2.1	2.3
22	48	1.2	1.1
23	36	1.2	1.3

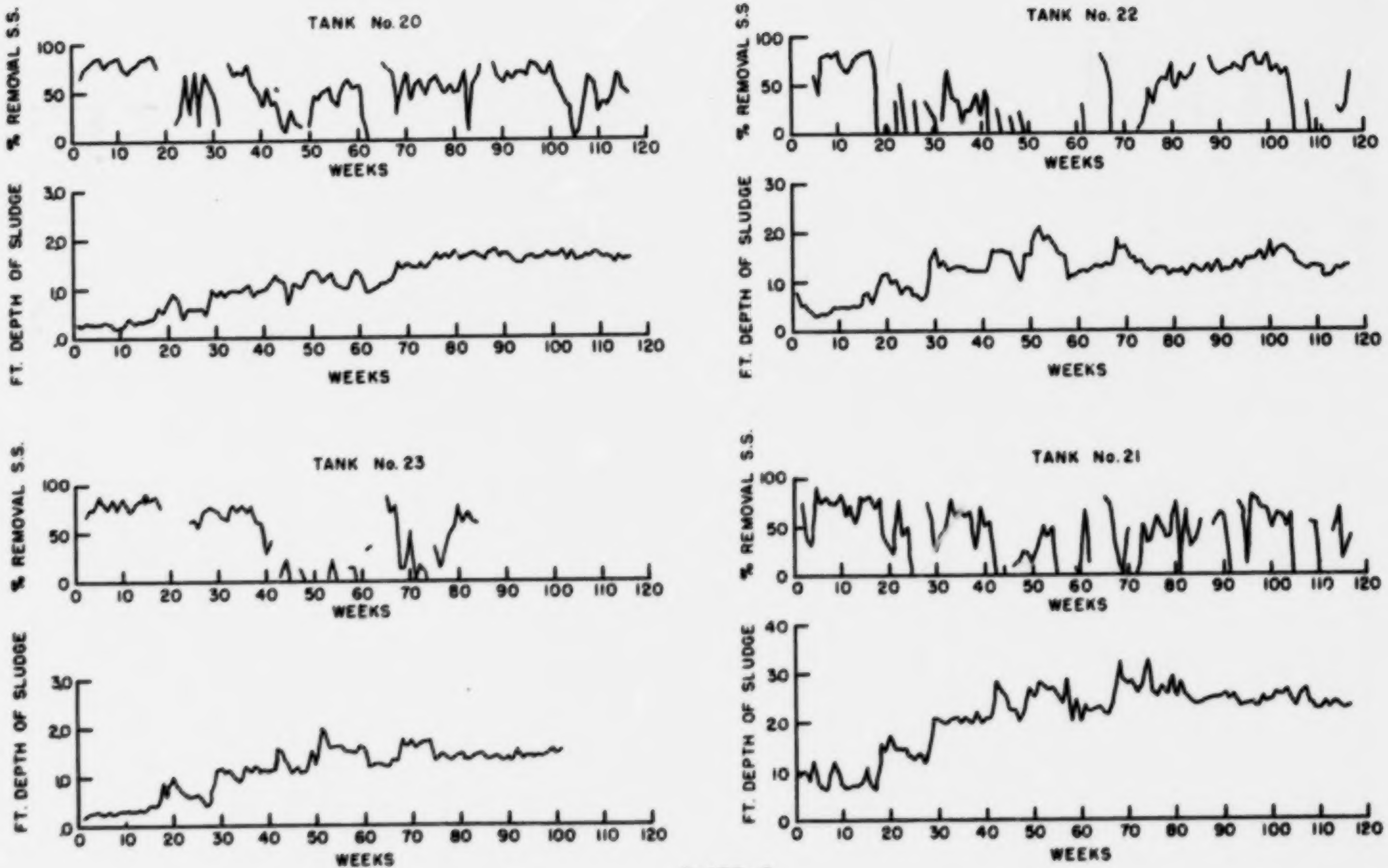

TANK No. 20
% REMOVAL S.S.
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
FT. DEPTH OF SLUDGE
3.0
2.0
1.0
.0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
TANK No. 22
% REMOVAL S.S
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
FT. DEPTH OF SLUDGE
30
20
10
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
TANK No. 23
% REMOVAL S.S.
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
FT. DEPTH OF SLUDGE
3.0
2.0
1.0
.0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
TANK No. 21
% REMOVAL S.S.
100
50
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS
FT. DEPTH OF SLUDGE
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90 100 110 120
WEEKS

PLATE 8

Through repeated sludge additions and prolonged operation, a limiting depth of sludge developed in each tank, above which sludge accumulated very slowly, if at all. From the volumes of sludge accumulated at the limiting depth, it appears that the 28½-inch liquid depth tank ranked highest, followed by the 64- and 36-inch-depth tanks, and lastly, the 48-inch-depth tank. It should be kept in mind that the outlet penetration for each tank was also a design variable, upon which information was desired. For purposes of the test, the outlet penetrations were designed for maximum sludge storage for each tank on the assumption that a limiting storage level would develop at some constant distance below the bottom of the outlet, taken as one foot, regardless of liquid depth. The experiment proved that such distance ("sludge clear space") was not constant. Hence, the maximum accumulations given in table 18 do not reflect equal opportunity among the tanks to develop maximum sludge storage. However, as will be shown in the development of a correlation between "sludge clear space" and liquid surface area, page 31, the sludge storage capacity trends shown here are qualitatively indicative.

Clear Space

INTRODUCTION

"Clear Space" is defined as distance between bottom of scum and top of sludge. As shown in plate 9, total clear space is composed of two parts, scum clear space and sludge clear space.

During the period February 1947 to July 1948, 300 single household septic tanks were opened and examined, as described in an earlier report (1). Sludge clear space which had developed in those tanks was plotted against time in service. An enveloping curve applied to this plot indicated that a minimum sludge clear space could develop,

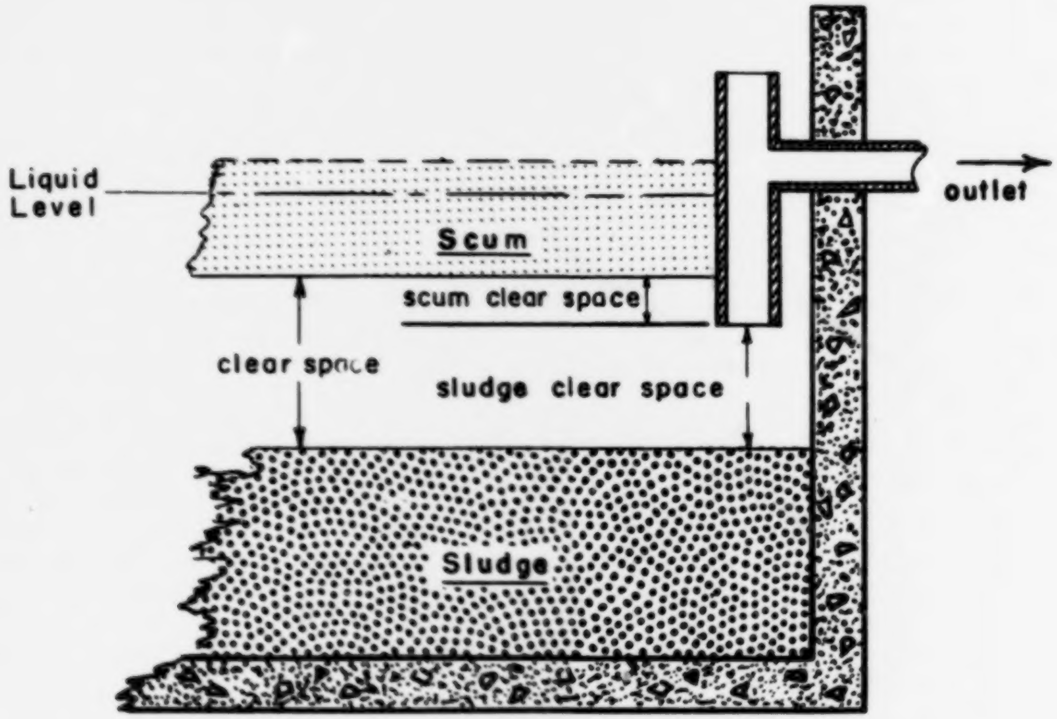


PLATE 9 – Clear Space

and possibly be constant at approximately one foot. This was further studied in the experimental tanks.

SLUDGE CLEAR SPACE

Effect of Scour.—A round, horizontal septic tank of approximately 500-gallon capacity equipped with a trapezoidal outlet baffle was filled to its entire liquid capacity with sludge obtained from septic tanks in the field. Sludge was added in several increments, each allowed to settle for 24 hours, removing supernatant liquid before adding the next increment. Details of the tank (No. 8) are shown on plates 1 and 52.

On September 24, 1950, feeds of raw sewage totaling 250 gallons per day were applied and samples were taken according to procedures described elsewhere (1). Sludge depth was measured after each feed. By the end of the third day, top of sludge had dropped to the bottom of the outlet baffle. After 2 weeks, a sludge clear space of approximately three-tenths of a foot had developed. During the succeeding 7 weeks, sludge level dropped slowly and leveled off at approximately six-tenths of a foot.

On November 27, 1950, rate of feed was raised from 10 to 20 gallons per minute. No change was made in the quantity of each feed, nor in the feed schedule. The feed rate of 20 gallons per minute was maintained for a period of 6 weeks. Sludge clear space remained approximately constant at two-thirds of a foot. The feed rate was increased to 30 gallons per minute on January 8, 1951, for 3 weeks. No significant change developed in sludge clear space.

The preceding portion of the experiment was conducted during winter under cold conditions. On January 29, 1951, feeds were returned to the normal laboratory rate of 10 gallons per minute, and the experiment was continued to observe behavior under influence of spring and summer temperatures.

During April and May 1951 sludge clear space continued to increase. As effluent temperatures continued to rise, the sludge level began to drop until equilibrium was reached at a sludge clear space of approximately one foot. The experiment was discontinued in July 1951.

Table 19 summarizes results of the tank clear space experiment.

TABLE 19.—Feed rate, temperature, and sludge clear space

Feed rate g. p. m.	Duration	Average effluent temperature	Sludge clear space developed
	Weeks	*F.°*	*Feet*
10	9	59	0. 60
20	6	51	. 65
30	4	54	. 65
10	23	67	1. 00

Table 19 shows that a sludge clear space developed at a feed rate of 10 gallons per minute, and remained approximately constant under subsequent dosing rates of 20, and still later 30, gallons per minute.

Sludge clear space was affected by temperature, increasing from two-thirds of a foot in winter to approximately 1 foot in summer.

Effect of Outlet Penetration.—From the concept of a minimum sludge clear space, it follows that maximum sludge storage capacity of any tank is governed by the penetration of the outlet baffling device below liquid surface.

Relatively poor results being obtained with the 4-foot-deep tank depth study, section B, page 27, cast suspicion on an outlet penetration of 13 inches. For that reason, a special investigation of two outlet penetrations was undertaken. Two 500-gallon septic tanks, identical except for outlet penetrations, were installed and performance observed. One of these, tank 17, was equipped with an outlet tee extending 13 inches below liquid surface, while that of the other, tank 18, penetrated 16 inches. Sketches of the 2 tanks are shown in appendix A, plate 46, and the layout in plate 1. Feeding, sampling, and sludge measuring procedures were identical with those described in a previous report (1).

For 48 weeks, prior to failure due to excess sludge accumulation, there was no appreciable difference in the performance of the two tanks, as measured by removal of suspended solids. The tank with the shallower penetration registered an efficiency of approximately 54 percent, compared with 51 percent for the deeper penetration.

The tank with the shallower penetration stored more digesting sludge (26.7 cubic feet) than the tank with the deeper penetration (23.5 cubic feet). After 78 weeks of operation, a clear space of 1.36 feet had developed in the shallower penetration tank, compared with 1.30 feet in the other. The difference, six one-hundredths of a foot, could be accounted for through experimental variability.

Tanks 20–23.—Operating results on tanks 20–23 during the depth study, section B, page 27, refute the concept of a minimum clear space constant for all tanks. The minimum sludge clear spaces developed were different for each tank. Except for the 48-inch-depth tank, which behaved abnormally throughout the depth study, the minimum sludge clear spaces reached provide evidence, as shown in table 20, that minimum sludge clear space varies inversely with tank surface area.

TABLE 20.—Surface area and sludge clear space

Depth Study

Tank No.	Tank liquid depth	Surface area	Minimum sludge clear space
	Inches	*Square feet*	*Feet*
20	28. 5	28. 1	0. 4
23	36. 0	22. 2	. 8
22	48. 0	16. 7	1. 8
21	64	12. 5	1. 5
Outlet penetration study			
17	48	16. 7	1. 4
18	48	16. 7	1. 3

Correlation Sludge Clear Space and Surface Area.—A review was made of sludge clear space which developed in all laboratory experiments on single-compartment, straight vertical-side septic tanks of approximately 500-gallon capacity. Data from the 11 applicable cases are shown in table 21.

TABLE 21.—Relationship of minimum sludge clear space to surface area

Tank No.	Period operated	Reported in part	Capacity	Surface area	Minimum sludge clear space
			Gallons	*Square feet*	*Feet*
2	1947–48	I	513	15. 5	1. 8
5	1947–48	I	525	16. 5	1. 3
6	1947–48	I	455	14. 7	1. 4
7	1947–48	I	539	18. 0	1. 2
9	1947–48	I	539	18. 0	1. 0
9A	1949–51	III	539	18. 0	1. 0
20	1950–53	III	500	28. 1	. 4
21	1950–53	III	500	12. 5	1. 5
23	1950–53	III	500	22. 2	. 8
17	1950–51	III	500	16. 7	1. 4
18	1950–51	III	500	16. 7	1. 3

A test for correlation between minimum sludge clear space and surface area produces a correlation coefficient of minus .901. The probability that these data are so arranged by chance alone is less than one in a thousand.

Using the method of least squares, the regression line equation is found to be:

$$\text{Sludge clear space} = 2.66 - 0.08A$$

where A is the surface area in square feet, and clear space is found in feet. The probability is 95 percent that mean minimum sludge clear space will not exceed the values given in table 22.

TABLE 22.—Mean minimum sludge clear space

Surface area	Mean minimum sludge clear space (95 percent confidence)	Surface area	Mean minimum sludge clear space (95 percent confidence)
Square feet	*Feet*	*Square feet*	*Feet*
12.5	1. 8	22.5	1. 0
15.0	1. 6	25.0	. 8
17.5	1. 3	27.5	. 7
20.0	1. 1	30.0	. 5

SCUM CLEAR SPACE

No experimental data have been found which would permit a treatment of scum clear space similar to that used for sludge clear space. In a few instances, systems in the field were observed where scum had reached the bottom of the outlet baffling device. However, in these cases, it was impossible to tell whether or not the soil absorption system was in the process of progressive degeneration and failure because of scum solids in the effluent.

If floating scum solids attained a thickness sufficient to put the bottom at or below the baffling device, danger of underscour would obviously exist. An arbitrary figure of three inches is suggested as a reasonable value for minimum scum clear space.

DISCUSSION

Data gained from field inspections illustrated the existence of a minimum sludge clear space. Coupled with an early laboratory experiment, these gave some indication that minimum sludge clear space might be constant, approximately one foot.

Results of the depth study refuted the concept of a constant minimum sludge clear space for all tanks. Minimum clear spaces were developed in each of the tanks, different for each one. A review of minimum clear space data in laboratory septic tanks reveals that clear space is an inverse function of surface area (or a direct function of depth in the case of tanks with straight vertical sides).

For 500-gallon septic tanks, the probability is 95 percent that the average minimum sludge clear spaces will not exceed values given in table 22, page 31. The minimum total clear space may be estimated by adding the allowance of 0.25 feet for minimum scum clear space to the values in table 22.

The below-water scum and sludge storage capacity of a tank may be determined by subtracting total clear space volume from total tank liquid capacity.

Small-Capacity Tank (Unseeded)

INTRODUCTION

Interest has been expressed in the effect of starting tanks without seed sludge, and in the behavior of small-capacity tanks operated at the expense of frequent cleaning.

PROCEDURES

Experimental Plant.—The tank used in this experiment was a round vertical type, 2 feet in diameter, 63 inches in liquid depth, having 123 gallons liquid capacity. This tank was referred to as tank 12 in previous studies (1). A sketch of the tank is shown in the appendix, plate 49, and its layout on plate 1.

Feeding and Sampling.—Feeding, sampling, and sludge and scum measuring procedures were identical with those described elsewhere (1).

Seeding and Sludge Additions.—Two trials were made. No seed sludge or subsequent sludge additions were made in either trial.

RESULTS

Started in Winter.—The first trial was started February 1949, and ended April 1950, a period of 60 weeks. Simultaneous plots of efficiency, as measured by suspended solids removal, and of sludge and scum accumulations against time in operation, are presented on plate 10. The sludge curve shows that there was a rapid accumulation of sludge during the winter months. With the arrival of early summer, the sludge bulk started to decrease and, at the same time, a heavy mat of scum formed. During the summer and fall months, the quantity of scum was as great as, if not greater than, the quantity of sludge in the tank. This scum apparently broke away and resettled as sludge, as evidenced in the disappearance of the scum and the sudden increase of sludge at the end of December. The sludge curve then flattened out at approximately 1.7 feet for the remainder of the winter.

The suspended solids removal curve shows that efficiency of the tank was relatively high and consistent during the winter of 1949, while sludge was building up in the tank. During early summer, sludge was lost from the tank, as indicated by negative suspended solids removals during the 10-week period from the latter part of June until the middle of August. A slow recovery in efficiency was recorded during the fall of 1949, reaching a high level in the winter of 1950.

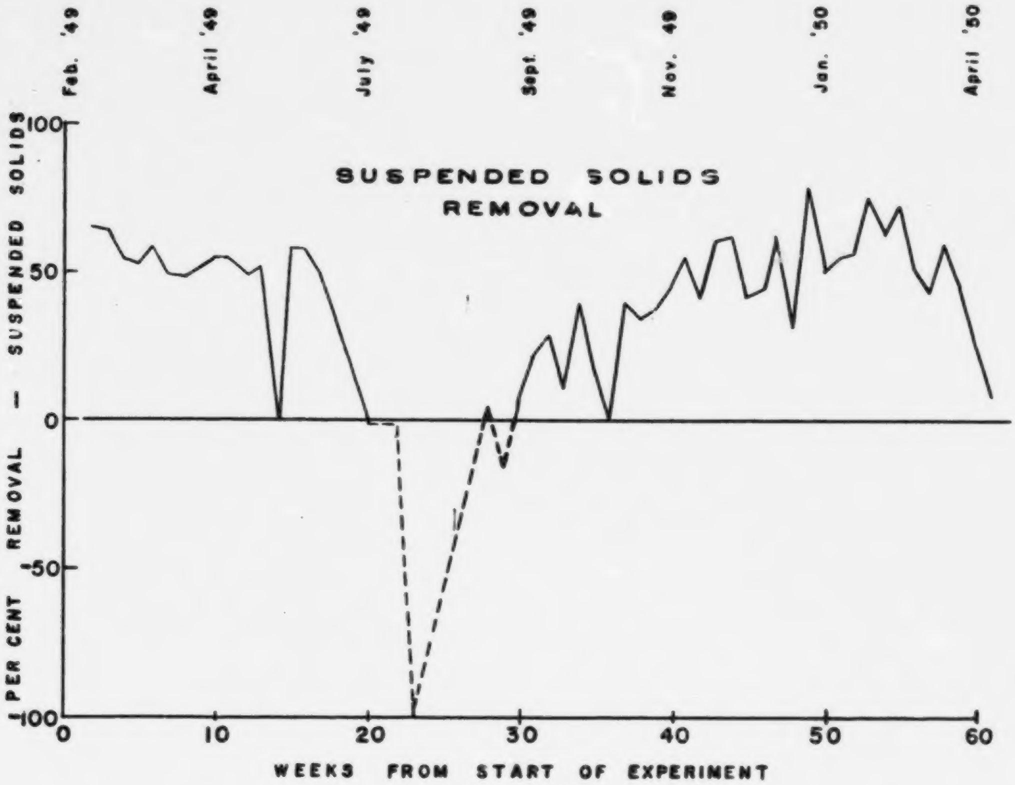
An acid condition prevailed in the tank during the scum-forming period. The pH of the sludge and scum was about 5.5 in the spring of 1949, returning to a normal of about 7.4 in August of 1949. Other septic tanks in normal operation under the same laboratory conditions have a slight hydrogen sulfide odor which is hardly objectionable. However, tank 12w was extremely malodorous during the scum-forming period.

Indication that digestion was proceeding slowly during the early spring of 1949 is shown by the high ratio of effluent suspended volatile solids to suspended solids on plate 11. The ratio gradually decreased as temperatures rose and digestion developed. The lower ratio persisted into the fall and early winter, despite lowering temperatures.

Plate 12 shows the relationship between efficiency of suspended solids removal and effluent temperature.

Started in Spring.—On May 8, 1950, the tank was drained, cleaned, and restarted without seed sludge. The second trial was conducted over a period of 60 weeks. The pattern of behavior during this period is shown on plate 13.

It may be seen that during the summer of 1950, efficiency was extremely erratic, and sludge accumulated very slowly. During the 10-week period, December 1950 to February 1951, suspended solids removals were uniformly good. A larger volume of sludge was accumulated than had been accumulated in the first 30 weeks of operation. In the spring of 1951 the efficiency curve started a



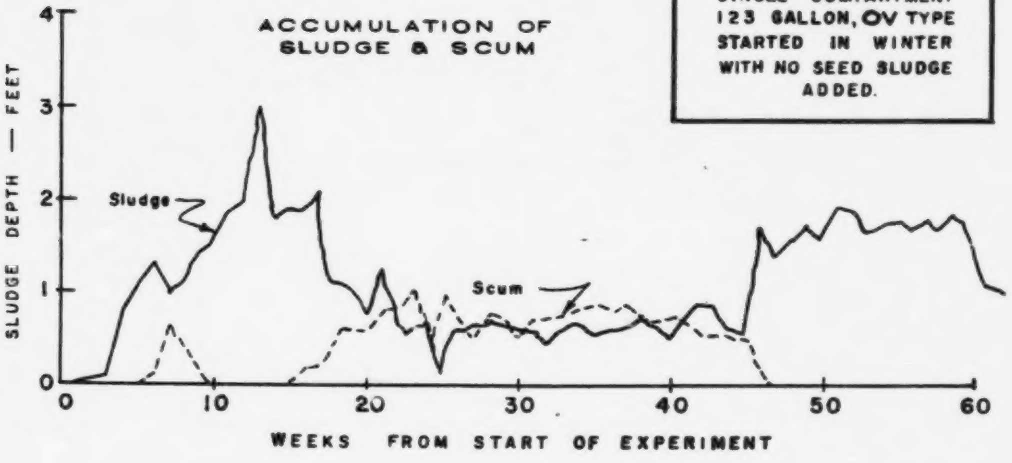


PLATE 10

PERFORMANCE CURVES
SINGLE COMPARTMENT
123 GALLON, OV TYPE
STARTED IN WINTER
WITH NO SEED SLUDGE
ADDED.

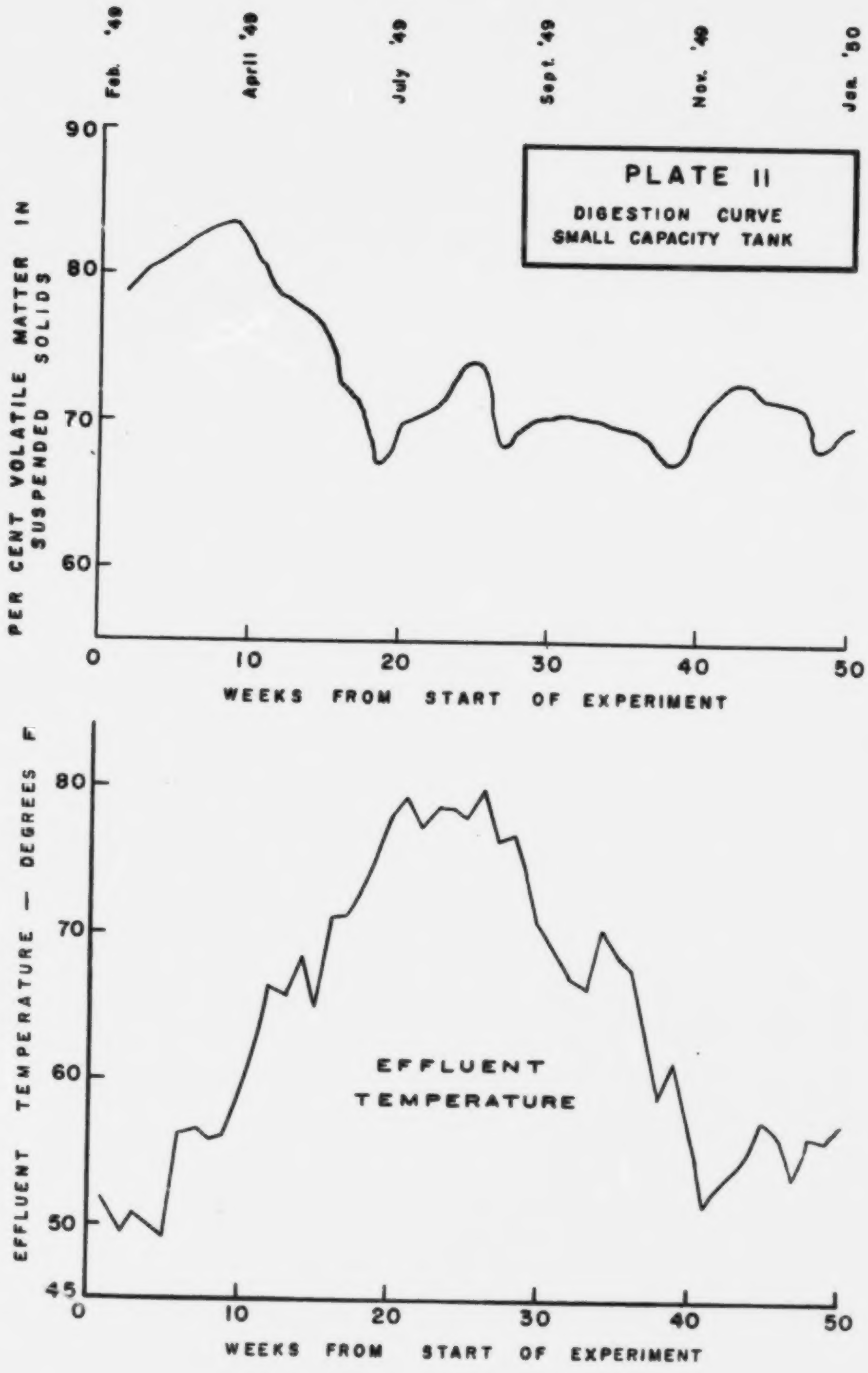


PLATE II
DIGESTION CURVE
SMALL CAPACITY TANK
Feb. '49
April '49
July '49
Sept. '49
Nov. '49
Jan. '50
PER CENT VOLATILE MATTER IN SUSPENDED SOLIDS
90
80
70
60
0
10
20
30
40
50
WEEKS FROM START OF EXPERIMENT
EFFLUENT TEMPERATURE — DEGREES F
80
70
60
50
45
0
10
20
30
40
50
EFFLUENT TEMPERATURE
WEEKS FROM START OF EXPERIMENT

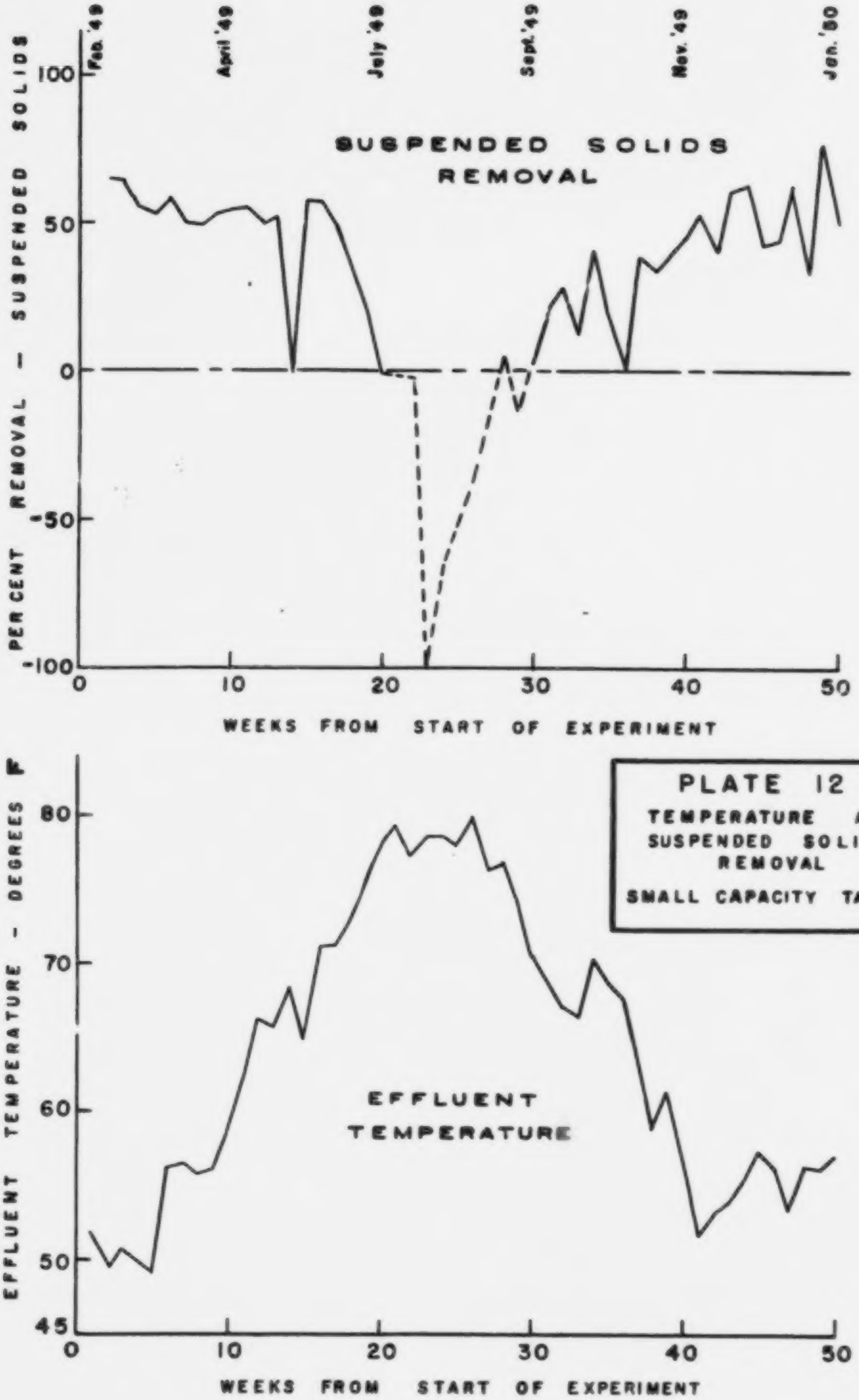


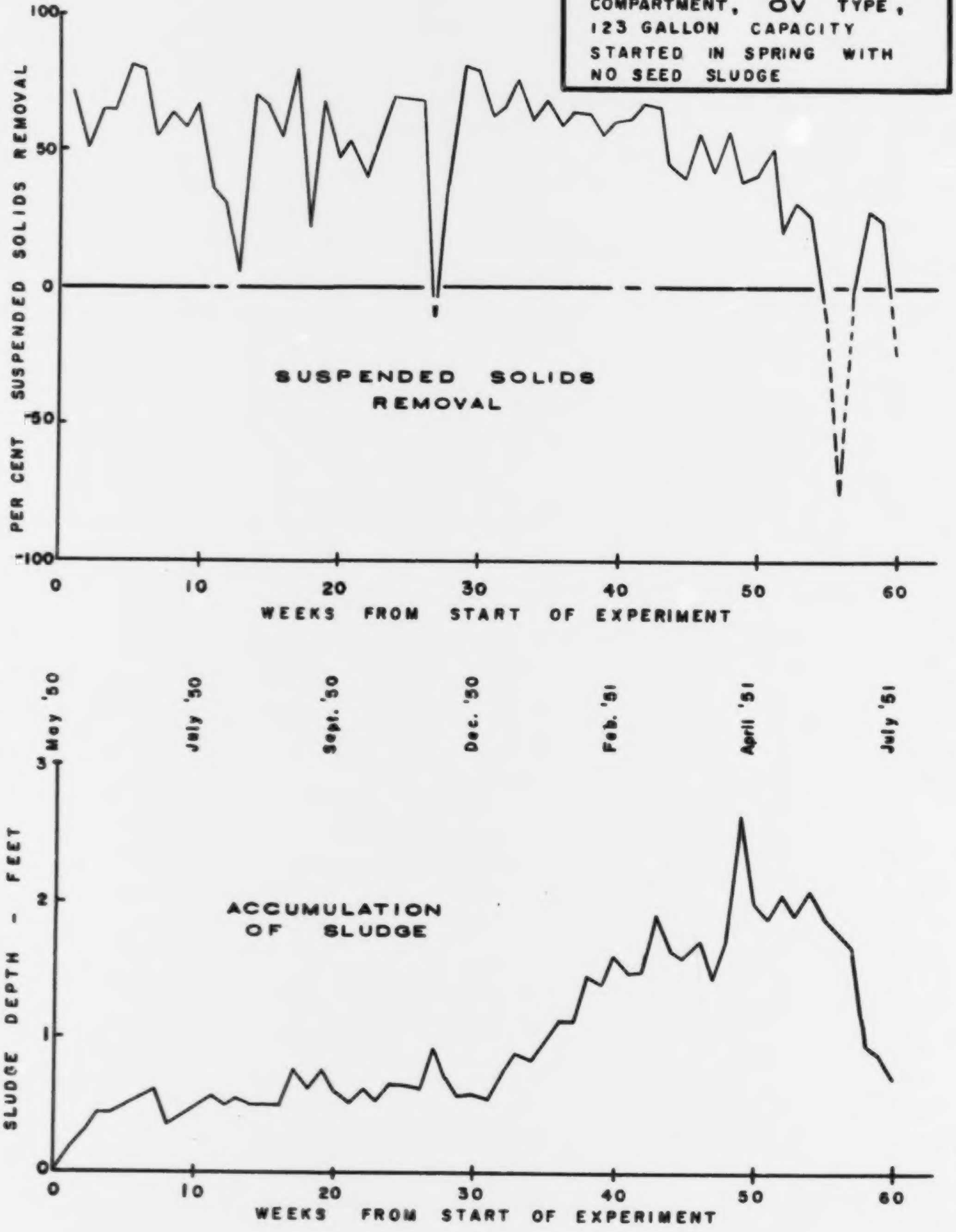
PLATE 12

TEMPERATURE AND SUSPENDED SOLIDS REMOVAL

SMALL CAPACITY TANK

PLATE 13

PERFORMANCE CURVES- SINGLE COMPARTMENT, OV TYPE, 123 GALLON CAPACITY
STARTED IN SPRING WITH NO SEED SLUDGE



gradual decrease coupled with a decreasing rate of sludge accumulation. Efficiency of suspended solids removal dropped sharply in April. At the same time, the sludge depth dropped rapidly and returned to approximately the level of the previous summer by the time the experiment was discontinued on July 2, 1951. In contrast with the first experiment there were no offensive odors nor any appreciable amount of scum formed during the spring upset period and sludge and effluent pH's remained near neutral during the entire experiment.

DISCUSSION

Several impressions may be drawn from study of these curves.

In the first trial, it may be noted that during the winter of 1949 digestion started slowly, as indicated by the rapid rate of sludge accumulation, the high percentage of volatile matter in effluent suspended solids and the relatively high efficiency of suspended solids removal. The development of excessive scum, offensive odors, and low pH's are indicative of acid (poor) digestion.

In contrast with this is the behavior noted early in the second trial, started in spring, wherein the lag in start of digestion appeared shorter; no scum nor offensive odors developed, and pH's of sludge and effluent were near neutral, all indicating better early performance.

The effect of temperature on the efficiency of suspended solids removal and sludge accumulation behavior is very clearly demonstrated. In both trials, the rapid accumulation of solids during the winter months, accompanied by relatively high suspended solids removals, was followed by discharge of a large portion of the accumulation during spring and summer, amounting to failure of the tank.

The pattern above mentioned has also been observed to a varying extent in other tanks. However, comparing the behavior of tank 12 in both trials with that of other single compartment tanks operated on this project (1), it is evident that seasonal variation is pronounced in tanks of small capacity and less severe in tanks of larger capacity.

The pattern observed may also be considered to reflect the behavior of a first compartment of a multicompartment tank. However, as subsequent compartments serve to retain the solids lost by the first compartment, the effect of seasonal upsets is minimized, resulting in higher year-round performance. This is discussed further in section A, page 19.

Another fact strongly accentuated by this experiment is the necessity of observing the behavior of a septic tank under winter conditions followed by summer temperatures, before a true appraisal of its performance can be made. In the trials described here, if the tank had been observed only in the winter months, it would compare favorably with the over-all performance of a much larger tank. However, with the advent of warm weather, the inadequacy of that comparison becomes obvious.

SECTION C

Sludge and Scum Accumulation

INTRODUCTION

A previous report in this series (1) dealt with average scum and sludge accumulations. A more complete analysis is presented here. Through the application of statistical methods, it has been possible to secure an estimate of normal variation to be expected, as well as regression line formulas.

Consideration of some of the variables governing the accumulation of sludge and scum will be helpful in evaluating the results which follow. Practical considerations made it necessary to obtain field data on sludge and scum accumulations on a volumetric basis, rather than on a dry solids basis. Under similar circumstances of origin, treatment, and storage, sludge and scum volumes would be, on the average, roughly proportional to dry solids weight. However, such measurements must be interpreted with caution, as the moisture content of septic tank sludge varies widely.

Other factors, such as resident persons, years in service, and tank capacity, can be measured, and their influence on accumulation considered. The measurements, themselves, are subject to variation. For instance, the dry weight of solids contributed per person must vary with age, personal habits, and time spent in the home. Seasonal conditions may affect volumetric measurement of sludge. Sludge tends to accumulate more rapidly during cold weather, so that the observed volume of sludge would vary, depending upon the season in which it was measured. Another important factor is the pattern of living in the particular home, such as cooking habits, garbage grinders, and visitors.

A wide variety of septic tank designs was encountered in collecting the data for this study. Tanks varied in size, shape, compartmentation, type of inlet, outlet, and intercompartment devices, and inlet-outlet penetration. Undoubtedly, some tanks performed better than others. However, when major variables are eliminated to enable comparison on the basis of construction details, the cases for each type of construction were too few to permit good analysis. Perhaps other factors, biochemical as well as physical, affect the volumetric accumulation of sludge and scum. It is evident from the partial listing above that field evaluation of tank features requires mass data to demonstrate trends.

Accumulation per Person

SAMPLE

This examination is based on 129 septic tanks which were inspected in the field. Originally, 300 tanks in normal operation and located at widely scattered points in the United States were inspected. Of these, 205 were screened out previously (1) for use in determining average sludge and scum accumulations. One of the overall objectives in the study of scum and sludge accumulation was to determine the effect, if any, of variations in water usage on tank performance. With this objective in mind, the examination reported here was limited to 129 of the 205 cases considered valid, where the quantity of water used was known. Effect of water consumption on accumulation is presented on page 47.

No attempt was made to restrict the 129 cases with respect to type, shape, compartmentation, capacity, or person loading. The statistical method applied made it necessary to restrict time in service o those in operation between one and nine years inclusively.

METHOD

Correlations between accumulation of both scum and sludge with time in service were determined. The regression lines were found by the method of least squares. Coefficients of correlation indicated that a straight line would adequately express the central trend.

A statistical treatment was applied which took into consideration divergence in the magnitude of variation with time in service. Cases were divided into groups by years of service. After nine years, cases were too few within each year to warrant this type of treatment. Each group was treated as a separate sample for which averages and estimates of the 95 percentile were calculated. Treating each of the averages as a single point, and using the method of least squares, the line of best fit was determined. In a like manner, a line was passed through the estimated 95 percentile values.

RESULTS

Equations thus derived are listed in table 23 and shown graphically on plate 14.

TABLE 23.—Rate of accumulation (cubic feet per person)

Type	Average	95 percent expected to be less than—[a]
Sludge	$ft^3/person = 2.12 + 0.70(t)$[b]	$ft^3/person = 5.19 + 1.09(t)$.[b]
Scum	$ft^3/person = 0.45(t) - 0.12$	$ft^3/person = 1.61 + 0.70(t)$.
Submerged accumulation (¾ scum + sludge)	$ft^3/person = 2.03 + 1.04(t)$	$ft^3/person = 6.40 + 1.61(t)$.

[a] From approximate estimates of the 95 percentile; rates of accumulation that will not be exceeded in about 95 out of 100 cases.

[b] Where t is time, in years.

In an earlier report (1), it was shown that 27.2 percent of the scum bulk floated above the liquid line in the tanks examined. Therefore, approximately three-quarters of the accumulated scum occupies liquid capacity in a septic tank. Thus, the basic formulas for sludge and three-quarters of the scum were combined to give the formula for submerged accumulation shown in table 23.

Accumulation per Bedroom

INTRODUCTION

The previous analyses were based on accumulation per person compared with time in operation. While good results are obtained by examining the systems on a per-person basis where the person-loading history is available, application to design must bridge the gap between a residence of known history and a proposed residence for which the future occupancy is indeterminate.

OCCUPANCY TIMES ACCUMULATION PER PERSON

Persons per Bedroom.—Table 56 of a previous report (1) shows the distribution of persons dwelling in various sized homes included in these studies. These data were taken from the standard questionnaire used in conjunction with the inspections of individual household systems. Further analysis of those figures yields the results tabulated in table 24.

The number of 5- and 6-bedroom homes encountered did not warrant the type of examination presented above. However, on the basis of the limited data available, the average number of persons per bedroom was 1.22 for 5-bedroom homes, and 0.84 for 6-bedroom homes. It is evident that, as the size of the home increases, the average number of persons per bedroom decreases. Considering variability among homes, allowances of more than 2 persons per bedroom would be required to include most of the spread.

TABLE 24.—Number of persons per bedroom

Number of bedrooms per home	Number of cases	Average number of persons per bedroom	Standard deviation	95 percent less than [a]—
2	170	1. 69	0. 54	2.58 persons per bedroom.
3	83	1. 41	. 38	2.04 persons per bedroom.
4	21	1. 24	. 53	2.11 persons per bedroom.

[a] See footnote, table 23.

If the equations representing accumulation per person, table 23, above, are multiplied by average occupancy, table 24, a new set of equations to express expected accumulation in cubic feet per bedroom can be derived. The resulting equations are contained in table 25.

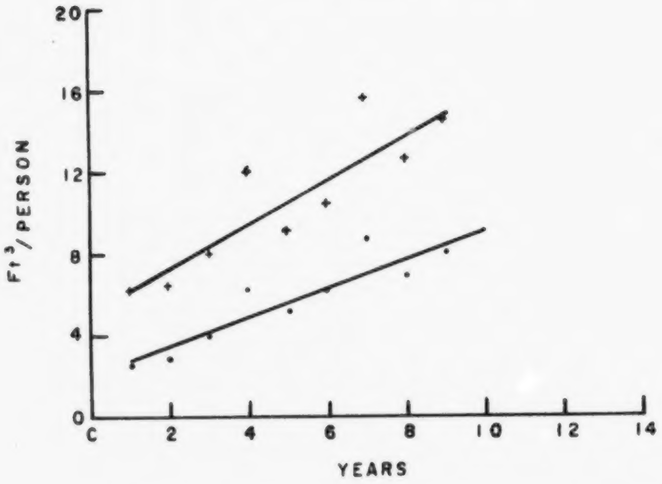
DIRECT CORRELATION, ACCUMULATION PER BEDROOM

Having the sludge accumulation figures from over 200 homes of varying sizes, it might be rea-

PLATE 14

ACCUMULATION PER PERSON

SLUDGE

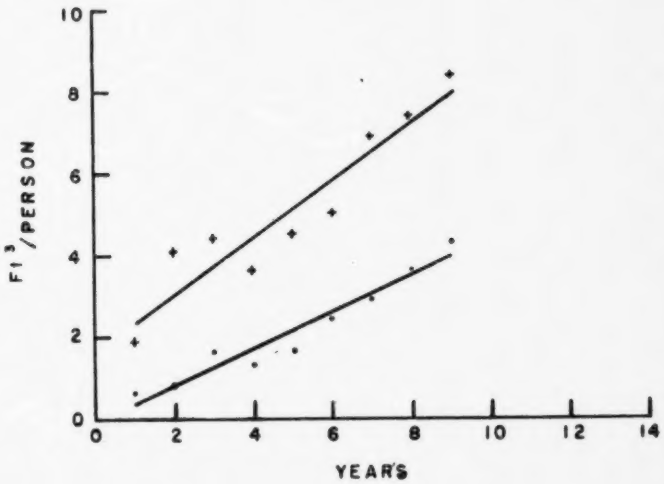


LINE OF BEST FIT

AVERAGE POINTS Y = 2.1 + 0.7 (t)

95% LESS THAN Y = 5.2 + 1.1 (t)

SCUM



LINE OF BEST FIT

AVERAGE POINTS Y = 0.4 (t) − 0.1

95% LESS THAN Y = 1.6 + 0.7 (t)

TABLE 25.—Rate of accumulation, cubic feet per bedroom (average occupancy times accumulation per person)

Size of home	Average	95 percent expected to be less than[a]—
2-bedroom		
Sludge	$ft^3/BR = 3.58 + 1.18(t)$[b]	$ft^3/BR = 8.77 + 1.84(t)$.
Scum	$ft^3/BR = 0.76(t) - 0.20$	$ft^3/BR = 2.72 + 1.18(t)$.
3-bedroom		
Sludge	$ft^3/BR = 2.99 + 0.99(t)$	$ft^3/BR = 7.32 + 1.54(t)$.
Scum	$ft^3/BR = 0.63(t) - 0.17$	$ft^3/BR = 2.27 + 0.99(t)$.

[a] See footnote, table 23.
[b] Where t is time, in years.

sonable to determine how the accumulation per bedroom varies with time in operation by direct correlation. Good design practice might favor such an approach, as the tank for a given home should be large enough to permit the rate of accumulation which experience shows could develop at one time or another from a house of that size. Variables, such as house guests, parties, and housekeeping habits, might be more accurately accounted for by considering a direct correlation, using size of house rather than number of persons registered as occupants.

Trials for Regression Line of Best Fit.—A preliminary investigation was made of the correlation between house size and accumulation. It was also desired to find if a curve of an appropriate form would have any practical advantage over a straight line. For this purpose, all 205 observations were used. Time in operation ranged from one-half to 39 years. House size varied from one to five bedrooms.

Accumulation of sludge in cubic feet per bedroom was plotted against years in service. This scatter diagram of all the points illustrated that accumulation increased at a fairly rapid rate during the first seven years in operation, with a tendency for the rate to fall off and the points to become more scattered after the eighth year. As it was not clear from visual examination whether a straight line or a semilog curve would give the best fit, trials were made using each type of curve.

Results of those trials are shown in table 26. A trial is also shown in which 137 tanks that had been in operation less than 8 years were considered.

Comparing the two equations for all 205 cases, it is seen from the coefficients of correlation, r_{xy}, that either of the curves fitted the data equally well. From the residual variances about the regression line, S_y, it is evident that the scatter of the points about the two lines is equal. As was expected, when tanks less than eight years old only were considered, the slope of the regression line increased and the intercept was lowered. Comparing coefficients of correlation, however, it appears that this curve fitted the 137 cases used no better than the other curves fitted all 205 cases. Scatter was reduced, as illustrated by a lower residual variance.

The preliminary examination illustrated that a good correlation exists between accumulation of sludge per bedroom and time in use, that the rate of accumulation during the first eight years is greater than the average rate, that the scatter about the regression line is greater after eight years, and that a straight line fits the data as well as a semi-log curve.

Accumulation per Bedroom, 2- or 3-Bedroom Homes.—The data were subdivided so that

TABLE 26.—Trials for curve of best fit (accumulation per bedroom versus period of service)

Type of curve	N[a]	r_{xy}[b]	S_y[c]	Equation of regression line
Straight line	205	0.546	5.24	$ft^3/BR = 5.37 + 0.67(t)$.[d]
Semilog curve	205	.540	5.24	$ft^3/BR = 3.23 + 9.39 \log(t)$.
Straight line using only cases under 8 years	137	.540	4.18	$ft^3/BR = 2.76 + 1.29(t)$.

[a] N—number of cases.
[b] r_{xy}—coefficient of correlation.
[c] S_y—residual variance about the regression line.
[d] t—time, in years.

TABLE 27.—Rate of accumulation (direct correlation of cubic feet per bedroom and time in service)

Size of home	Average	95 percent expected to be less than[a]—
2-bedroom		
Sludge	$ft^3/BR=3.42+1.28(t)$[b]	$ft^3/BR=9.93+1.44(t)$.
Scum	$ft^3/BR=0.74+0.51(t)$	$ft^3/BR=2.04+1.08(t)$.
3-bedroom		
Sludge	$ft^3/BR=3.57+0.59(t)$	$ft^3/BR=7.52+1.02(t)$.
Scum	$ft^3/BR=0.19+0.60(t)$	$ft^3/BR=3.00+0.80(t)$.
All homes		
Sludge	$ft^3/BR=3.62+1.03(t)$	$ft^3/BR=9.08+1.41(t)$.
Scum	$ft^3/BR=0.35+0.59(t)$	$ft^3/BR=1.81+1.07(t)$.

[a] See footnote, table 23.
[b] Where t is time, in years.

further analysis could be limited to a particular house size. Figures were available for 114 2-bedroom homes and 46 3-bedroom homes. Only the 2- and 3-bedroom groups and a combination of all homes contained enough cases to permit comparative analysis.

Again, in order to compensate for increasing divergence, cases were divided into subgroups depending on time in service. The subgroup for each year was then treated as a separate sample. To obtain yearly samples large enough for statistical treatment, it was necessary to limit time in service from one to nine years inclusive. Equations for the average and values covering most cases (95 percentile) were obtained using the procedure outlined in section C, page 38. These equations are summarized in table 27, and are shown graphically on plates 15 and 16.

Although equations presented in tables 25 and 27 resulting from the two independent approaches differ slightly, no true significance can be attached to the difference. This can be illustrated by comparing results obtained with any two comparable equations. For example, the expected accumulation of sludge per bedroom in two-bedroom homes is computed using average equations and tabulated for comparison in table 28.

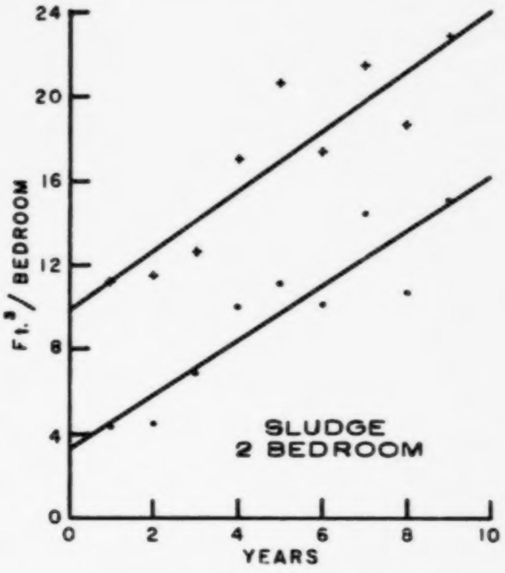
After nine years, the total difference is only 0.74 cubic feet per bedroom, and average difference, 0.34. At nine years, the residual variance about the regression line is approximately 4.8 cubic feet. It is evident, therefore, that within the period 1 to 9 years the difference between the 2 equations is small.

In the following study of the ratio of submerged scum to total submerged accumulation, it is demonstrated that the equations evolved on a per person basis give a more reasonable relationship than those derived from a direct correlation of accumulation per bedroom with time in service. On that basis the preferred equations are those shown in table 25, page 41.

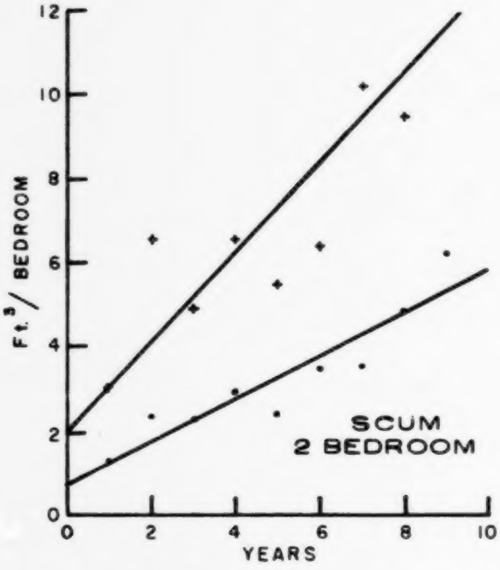
TABLE 28.—Comparison of sludge accumulations computed by equations in tables 25 and 27

After years in service	(From table 25) $ft^3/BR=3.58+1.18(t)$	(From table 27) $ft^3/BR=3.42+1.28(t)$	Difference
1	4. 76	4. 70	−0. 06
2	5. 94	5. 98	. 04
3	7. 12	7. 26	. 14
4	8. 30	8. 54	. 24
5	9. 48	9. 82	. 34
6	10. 66	11. 10	. 44
7	11. 84	12. 38	. 54
8	13. 02	13. 66	. 64
9	14. 20	14. 94	. 74

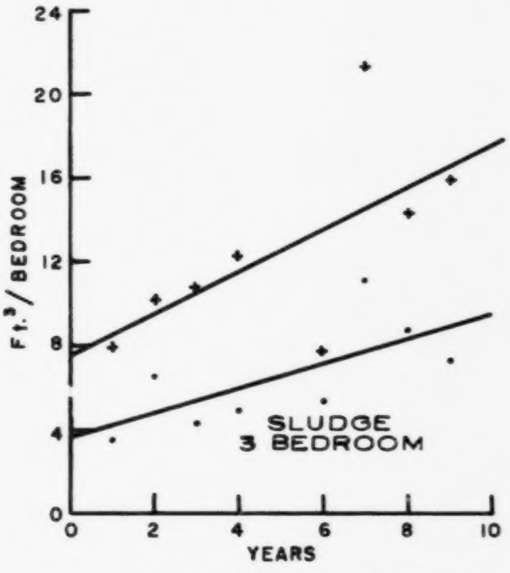
PLATE 15
SLUDGE AND SCUM ACCUMULATION
2 AND 3 BEDROOM HOMES



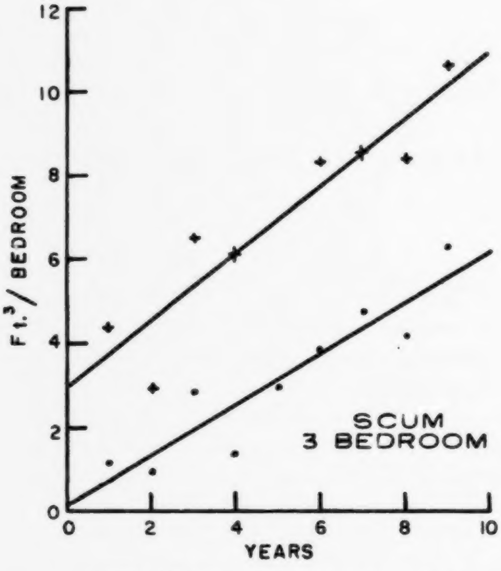
AVERAGE LINE $Y=3.42+1.28(t)$
95% LESS THAN LINE $Y=9.93+1.44(t)$



AVERAGE LINE $Y=0.74+0.51(t)$
95% LESS THAN LINE $Y=2.04+1.08(t)$



AVERAGE LINE $Y=3.57+0.59(t)$
95% LESS THAN $Y=7.515+1.02(t)$

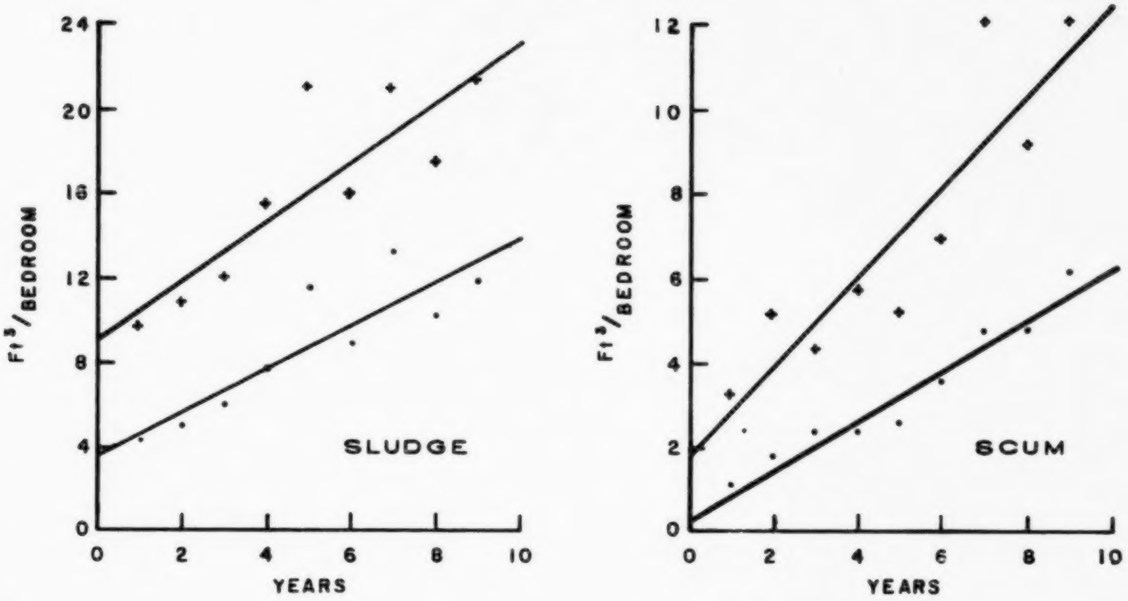


AVERAGE LINE $Y=0.19+0.60(t)$
95% LESS THAN $Y=3.00+0.80(t)$

PLATE 16

SLUDGE AND SCUM ACCUMULATION

ALL HOMES



AVERAGE LINE Y = 3.62 + 1.03 (t)

95% LESS THAN Y = 9.08 + 1.41 (t)

AVERAGE LINE Y = 0.35 + 0.59 (t)

95% LESS THAN Y = 1.81 + 1.07 (t)

Ratio of Submerged Scum to Total Submerged Accumulation

INTRODUCTION

In a septic tank, solid material is separated from the liquid portion of sewage by gravity. Settleable solids form a blanket of digesting sludge in the lower portion of the tank. Floating solids and gas-lifted sludge particles form a surface mat known as scum. An outlet baffle, pipe fitting, or similar device is customarily provided to prevent escape of scum solids. Such devices should penetrate the liquid far enough to retain the expected accumulation of scum. Penetration beyond such point will unnecessarily reduce sludge storage capacity (sec. B, p. 29). For maximum utilization of tank capacity, the outlet should penetrate to a depth which will allow an equal time in service for both sludge and scum storage.

This balance in design can be obtained by establishing the relationship between rates of submerged scum and sludge accumulation. The relationship has been investigated in two ways. First, by computing the ratio of submerged scum to total submerged accumulation for individual tanks. The individual ratios were then compared with each other and with time in service. The second method involved computing the relationship from the formulas derived for accumulation shown in tables 25 and 27.

RATIO OBTAINED FROM INDIVIDUAL TANKS

The frequency distribution shown in table 29 was obtained using tanks which had been in normal household operation more than 2 and less than 14 years. Water use was known. A variety of types, capacities, loadings, and geographical locations are included.

TABLE 29.—Frequency distribution, ratio of submerged scum to total submerged accumulation

Ratio	Frequency f	Σf	Percent, less-than—
0	11	11	0
0.100	23	34	18
0.200	30	64	39
0.300	31	95	63
0.400	17	112	81
0.500	11	123	92
0.600	1	124	97
0.700	3	127	99

From grouped data, the arithmetic mean is found to be 0.2567 and the median value 0.2483. From ungrouped data, the arithmetic mean was found to be 0.2578 with a standard deviation of 0.1676.

A plot of individual ratios and time in service, shown on plate 17, suggested a positive correlation. Further analysis produced a coefficient of correlation of 0.242 which is significant at the two percent level. A regression line equation, as determined by the method of least squares, is:

Ratio $= 0.1498 + 0.01593\,Y$ (where $Y =$ years)

Residual variance about the regression line is 0.1082.

RATIO OBTAINED FROM EQUATIONS

If the equations representing accumulation in cubic feet per person are multiplied by the average number of persons for a given sized home, equations result which may be used to predict the rate at which sludge and scum will accumulate, table 25. In table 30, these equations have been converted to give an estimate of the submerged scum, that portion of scum occupying liquid capacity of the tank, and sludge which will accrue from a two-bedroom home.

TABLE 30.—Equations for submerged accumulation for 2-bedroom homes

Type of accumulation	Average	95 percent are expected [a] to be less than—
Scum [b]	$Ft^3/Home = 1.14\,(t) - 0.30$	$Ft^3/Home = 4.08 + 1.76(t)$.
Sludge	$Ft^3/Home = 7.16 + 2.37(t)$	$Ft^3/Home = 17.54 + 3.68(t)$.
Combined	$Ft^3/Home = 6.86 + 3.51(t)$	$Ft^3/Home = 21.62 + 5.44(t)$.

[a] See footnote, table 23.

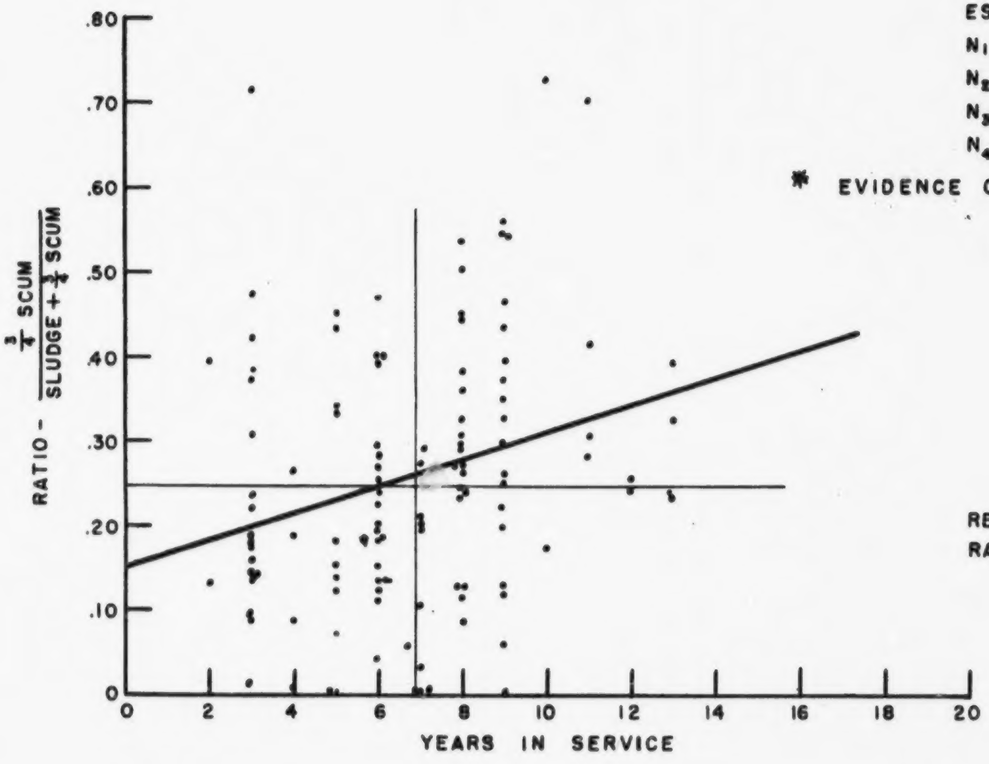
[b] Submerged portion (¾ of total).

The equations in table 30 may be used to compute the proportion of tank storage capacity which should be allotted to submerged scum in order to secure a balance between the cleaning intervals based on scum accumulation and on sludge accumulation. For example, a 500-gallon tank with 30-inch liquid depth has a liquid surface area of 26.7 square feet. Entering table 22, minimum sludge clear space is 0.73 feet. Adding 0.25 feet scum clear space, total clear space is 0.98 feet, or 26.2 cubic feet volumetrically. Deducting from 66.8 cubic feet total capacity the net submerged solids storage capacity is 40.6 cubic feet, equivalent to 9.6 years operation at table 30 average accumulation rate. The ratio of submerged scum to submerged scum plus sludge, using table 30 equations, is 0.26 at 9.6 years.

Ratios obtained from several of the accumulation equations are presented in table 31 for comparison. Agreement is considered generally good. The variations existing probably originate in variation in samples and statistical approaches. Within the practical limits of periods of service represented in the basic data, the ratio tends to increase with time. A ratio based on a short period of service (high accumulation rate) would therefore be lower than that based on a longer period of service at an average accumulation rate. This is apparent in table 31. For practical design purposes, a ratio of 0.27 appears reasonable.

PLATE 17

CHANGE IN PROPORTION OF SCUM TO TOTAL SUBMERGED ACCUMULATION WITH TIME



ESTIMATE OF CORRELATION

$N_1 = 40$ $\quad \frac{80}{127} = .6299$

$N_2 = 23$

$N_3 = 40$ $\quad e = .44$ (EST.) *

$N_4 = 24$

* EVIDENCE OF POSITIVE CORRELATION

REGRESSION LINE EQUATION

RATIO = .1498 + .01593 YEARS

TABLE 31.—Ratios of submerged scum to total submerged accumulation obtained by various methods

Origin of equation	Equation shown in—	Mean ratio obtained by equations for—	
		Average case	95 percent less than[a]—
2-bedroom homes	Table 27	0.212	0.240
All homes	do	.258	.250
Per person multiplied by average occupancy.	Table 25	.266	.256
Direct correlation of ratio with time.	Plate 17	.325	.223
Mean		.265	.242

[a] See footnote, table 23.

Effect of Increased Water Use on Accumulation of Sludge and Scum

EXPERIENCE IN THE FIELD

A comparison of winter water consumption data for 15 "conventional washer" homes against 15 "automatic washer" homes in Duval County, Fla., revealed that there was an increase in water use in the "automatic washer" homes. The average increase was 25 gallons per bedroom per day. In order to cover most cases (95 percentile) an increase of about 93 gallons per bedroom per day is indicated. The increase is probably due to change in home laundry habits, with more frequent washes spread throughout the week. In the homes mentioned above, it was found that those with conventional-type washing machines average 2.5 loads per week, with a range of ¼ to 7 loads per week. Homes with automatic washers averaged 5.5 loads per week, with a range of 1 to 15 loads per week.

In preliminary investigations, the per capita annual sludge and scum accumulation was compared with theoretical retention time (tank capacity divided by daily metered winter water consumption). These trials indicated existence of a positive relationship between accumulation and retention time. However, it was impossible to say whether the relationship was due to differences in capacity, or in water use. It was established in a previous report (1) and on page 13 of this report that an increase in tank capacity is accompanied by an increase in accumulation. Retention time also increases as capacity increases. Therefore, an increase in accumulation accompanying increased retention time could be due to capacity and independent of water use.

A multiple correlation was made between the rate of accumulation as the dependent variable, and persons, capacity, and water consumption as independent variables. As the calculations are long and involved, 37 cases were chosen at random for a trial sample. This sample was considered large enough to demonstrate the presence or absence of correlation.

Sample characteristics of the 37 cases chosen for the trial are shown in table 32.

TABLE 32.—Characteristics of sample for multiple correlation

Item	Mean	Standard deviation	Range
Time in service (t)	6.76 years	2.60 years	2–12 years.
Persons (p)	3.6		
Capacity (c)	568.5 gallons	165.2 gallons	224–930 gallons.
Total daily winter water use ($100w$)	136.0 gallons		
Winter water use	39.1 g. p. d	23.9 g. p. d	8–149 g. p. d.

The range in metered winter water consumption, 29.6-153.8 g. p. d., observed in the 15 automatic washer equipped Florida homes, is comparable with the sample range, 8-149 g. p. d., indicated in table 32. It should be borne in mind that tank sewage flows may be less than metered winter water consumption values, because of variations in water use and disposal arrangements among households.

Line of best fit for total accumulation of sludge and scum was found to be:

$$\text{ft.}^3/\text{year} = 0.58p + 1.16c + 0.01w - 3.08$$

Where

p = persons

c = capacity in hundreds of gallons

w = total daily winter water consumption, hundreds of gallons

Cursory examination of the regression equation leads to the conclusion that the coefficient for water has no significance. This observation was borne out by statistical analysis, wherein the coefficients for capacity and persons were found to be highly significant, but no significance could be attached to that for water. Thus, there is no correlation between water consumption and solids retention in the range covered by this sample.

EXPERIENCE IN THE LABORATORY

During the period June 10 to August 18, 1947, experimentally operated septic tanks were started at a loading rate of 500 gallons per day. Eight feeds daily were made at approximately 2-hour intervals, each feed applied at a rate of flow of about 10 g. p. m. During this initial series, the removal of suspended solids was poor and erratic. Subsequent series were conducted at a loading rate of 250 gallons per day, also in 8 feeds daily at 10 g. p. m. The reduction was made by halving each of the individual feeds. All tanks showed a general improvement in performance. The improved performance was probably due to smaller feeds, although the influence of starting new tanks, on the performance during the initial period, cannot be neglected. These results are recorded in an earlier report (1).

During the summer of 1952, the total quantity of sewage fed was continued at 250 gallons, but the interval between intermittent feeds was reduced from 2 hours to 1 hour. No adverse effect was noted in the performance of any of the tanks.

One interpretation of these observations is that performance is more sensitive to the amount of sewage received in each dose, than it is to the overall quantity of sewage received. More investigation is needed to establish or refute this observation.

Combined Effect of Time, Persons, and Capacity on Submerged Accumulation

INTRODUCTION

In the previous section, it was demonstrated that the annual rate of accumulation of sludge and scum was not affected by observed water consumption. In the same treatment, it was demonstrated that persons and tank capacity did materially effect rate of accumulation. With water consumption eliminated, there remain three measurable factors which may influence accumulation. These are time, persons, and liquid capacity of the tank. The following treatment was made to determine the magnitude of the interrelated effect of each of these variables on total submerged accumulation.

METHOD

Submerged accumulation in a tank is approximately equal to three-quarters of the accumulated scum plus the total accumulation of sludge. It is the submerged accumulation which occupies liquid capacity of a tank and, for that reason, is the variable for which an estimate is desired. Therefore, submerged accumulation expressed in cubic feet is treated as the dependent variable. Independent variables are number of persons using tank, time in service (years since start or last cleaning), and liquid capacity of the tank expressed in hundreds of gallons $\left(\frac{\text{gallons}}{100}\right)$.

A straight line relationship,

$$y=a(t)+b(p)+c(C)+d$$

was assumed. Regression coefficients and the constant were evaluated, using the method outlined by Brownlee (3).

Sample Characteristics.—Characteristics of the sample are shown in table 33.

RESULTS AND DISCUSSION

The equation developed for estimating submerged accumulation when time in service, number of persons, and liquid capacity of tank are known is:

$$y=3.4(t)+2.2(p)+4.0(C)-20.9$$

Residual variance was found to be 9.72. Regression coefficients, with their standard error and student's t, are shown in table 34.

TABLE 33.—Characteristics of sample

Variable	Unit	Mean	Standard deviation	Range
Accumulation (y)	Cubic feet	31. 60	14. 08	6.7 to 68.9.
Period of service (t)	Years	6. 71	2. 54	2 to 13.
Persons using (p)	Each	3. 83	1. 28	2 to 9.
Capacity (c)	$\frac{\text{gallons}}{(100)}$	5. 30	1. 65	2.2 to 12.6.

TABLE 34.—Regression coefficients

Variable	Regression coefficient	Standard error	Student's t ($n=127$)
Period of service (t)	3. 4	0. 3479	9. 9135
Persons (p)	2. 2	. 6841	3. 1449
Capacity (C)	4. 0	. 5335	7. 4560

The constant was evaluated and found to equal −20.9.

The equation should be used within the range of variables from which it was developed, as indicated in table 33. The average case agrees closely with those of equations previously derived. Substituting average occupancy of a 2-bedroom home, 3.38 persons, and a 530-gallon tank, the equation becomes:

$$y=3.4(t)+2.2(3.38)+4.0(5.3)-20.9$$

or

$$y=3.4(t)+7.7$$

This is in good agreement with an equation for total submerged accumulation, which may be derived from the equations for 2-bedroom homes in table 27, page 42:

$$y=3.3(t)+7.9$$

It also is in good agreement with an equation which may similarly be derived from the equations for 2-bedroom homes in table 25, page 41:

$$y=3.5(t)+6.9$$

SECTION D

Appraisal of Soil Absorption Capacity

INTRODUCTION

The capacity of a soil to absorb effluent is an important criterion in the proper design of septic tank-soil absorption systems. Successful operation requires that the soil completely absorb the effluent discharged from the septic tank for a comparatively long time. Individual soil absorption system size is based on household size and the rate at which soil at that site can be expected to absorb effluent.

The capacity of a soil to absorb effluent is determined indirectly. First, the rate that a soil will absorb water is measured by a percolation test. The rate that the same soil can be expected to absorb effluent over a prolonged period is then estimated from a previously developed empirical relationship. In most cases, the size of the absorption field needed is estimated directly from tables which take into account the percolation rate, empirical relationship, expected sewage flow, etc.

Although a percolation test is the only known means for obtaining a quantitative appraisal, there are other means by which a rough appraisal of soil-moisture absorption potentiality can be made, which generally have not been utilized in the sewage disposal field.

SOIL MAPS

The capacity of a soil to absorb and transmit water is an important problem in agriculture, particularly in relation to irrigation, drainage, and other land management practices. Through studies in these fields, a variety of aids have been developed for judging the absorption of water transmission properties of soils which could be helpful in the sewage field. Considerable information has been accumulated by agricultural authorities on the relative absorption capacities of specific soils in many areas of the United States. Much of this information is included in Soil Survey Reports and Maps (4) published by the United States Department of Agriculture in cooperation with the various State Agricultural Colleges. The general suitability of specific soils for effluent disposal may often be interpreted from these reports and maps.

CLUES TO ABSORPTION CAPACITY

Considerable information about relative absorption capacities of soils may also be obtained by a close visual inspection of the soil. The value of such an inspection depends upon some knowledge of the pertinent soil properties. The main properties indicative of absorption capacity are soil texture, structure, and color.

Texture.—Soil texture, the relative proportion of sand, silt, and clay, is the most common clue to water absorption capacity. The size and distribution of particles govern the size and distribution of pores which, in turn, govern the absorption capacity. The larger the soil particles, the larger are the pores and the faster is the rate of absorption. Texture can best be judged by the feel. The lighter or sandier soils have a gritty feel when rubbed between the thumb and forefinger; silty-type soils have a "floury" feel and, when wetted, have no cohesion; heavier clay-type soils are dense and hard when dry and have a slick, greasy feel when wetted. The use of texture as a clue to absorption qualities has its limitations; it is primarily reliable in the sandier soils. In the heavier-type soils, including sandy soils containing appreciable amounts of silt or clay, one must look for additional clues, such as structure and soil color, as indicators of absorption capacity.

Structure.—Soil structure is characterized by the aggregation or grouping together of textural particles, forming secondary particles of larger size. Such secondary particles then tend to govern the size and distribution of pores and, in turn, the absorption properties. Structure can easily be recognized by the manner in which a clod or lump breaks apart. If a soil has structure, a clod will break with very little force along well-defined cleavage planes into uniformly sized and shaped units. If a soil has no structure, a clod will require more force to break apart and will do so along irregular surfaces with no uniformity in size and shape of particles.

In general, there are four fundamental structural types, named according to the shape of the aggregated particles: platy, prism-like, block-like, and spheroidal. A soil without structure is generally referred to as massive. Spheroidal structure tends to provide the most favorable absorption properties, and platy structure, the least. Although other factors, such as size and stability of aggregates to water, also influence the absorption capacity, recognition of the type of structure is probably sufficient for a general appraisal.

Color.—One of the most important practical clues to water absorption is soil color. Most soils contain some iron compounds. This iron, like a piece of iron in a tool or piece of machinery, if alternately exposed to air and to water, oxidizes and takes on a reddish-brown to yellow color. Thus, if a soil has a uniform reddish-brown to yellow oxidized color, it indicates that there has been free alternate movement of air and water in and through the soil. Such a soil has desirable absorption characteristics. At the other extreme are soils of a dull gray or a mottled coloring, indicating lack of oxidizing conditions or very restricted movement of air and water. These soils have poor absorption characteristics.

Information obtained through inspection or from soils maps and reports can be of particular value in preliminary appraisal of soils for sewage disposal. For instance, in many cases, unsuitable soils may be immediately ruled out on the basis of such information; in other cases, selection of the best of several sites may be made on the basis of the inspection. Absorption capacity information obtained in this manner is relative. For quantitative information upon which to base specific design, we still must depend on some direct measurement, such as a water absorption rate as measured by a percolation test.

DIRECT MEASUREMENT OF WATER ABSORPTION CAPACITY

Information on methods for estimating the rates at which a soil will absorb water is available from agricultural and related fields. A wide variety of procedures has been used. The procedures are, in general, of two types: (1) measurements made on samples of soil removed from their natural position, and (2) measurements made on the soils in place. Unfortunately, neither type of procedure is completely satisfactory for all purposes.

Measurements on samples are of value primarily for that segment of soil sampled. The natural interrelation of the various soil layers in place is lost in the sampling procedure. Percolation rate values determined for samples apply only to that layer of soil from which the sample is taken. The capacity for water intake of the over-all soil profile must be estimated from consideration of the permeability and position of the individual layers that make up the soil profile. Such estimates (5) (6) are of particular value in classifying soils as to relative permeabilities, but are of limited value in arriving at quantitative values.

Water absorption measurements of soils in place are time-consuming. However, for quantitative data, there appears to be no substitute for a field test. Although many factors which influence such tests are not yet fully understood, it is not difficult to take measurements that have practical significance.

The principal field methods involve sprinkling to simulate rain, flooding or impounding water on the soil surface, measuring water delivery to and discharge from irrigated areas, or measuring the rate that water will flow out of holes or excavations in the soil at specific depths. Methods of determining the rate and amount of absorption of water by surface soils are generally referred to as infiltration methods. Methods of determining rate and amount of absorption by subsoils or successive layers of soil generally are referred to as permeability or percolation methods. Richards (7) has pointed out that soils and the factors that affect infiltration and percolation rates are so variable that, even though a large amount of work has been done on measuring rates, there are no standardized methods applicable to all situations.

It has been pointed out (8) that the length of time a test is conducted depends on the purpose of the test and the kind of information that is sought. In appraising irrigation problems, a depth of water or a length of time for one irrigation may be sufficient test. For appraising soil drainage or leaching problems, the test should be conducted over a period of time sufficient to reflect the anticipated problem condition of the soil.

Edlefson, in discussing the paper by Huberty and Pillsbury (9), states: "When water is first applied to a field plot (surface soil), the rate of infiltration is comparatively rapid and gradually decreases with time to an asymptotic or approximately steady value which seems to be more or less characteristic of the plot at that particular time. Hence it seems difficult to choose any particular point on the rate-of-transmission curve as a function of time as having any particular meaning other than the asymptotic or steady value." Edlefson further indicates that this value is only reached after a time which is usually longer than required for an ordinary irrigation to penetrate into the soil. He concludes that, "The best that the experimenter can do, when ordinary applications of water are applied, is to measure an average rate of penetration." Thus, the test is conducted for a specific purpose, in this case irrigation studies.

INFILTRATION METHODS

Investigators dealing with problems other than irrigation water application have considered it necessary to conduct tests over an extended period to determine the asymptotic or steady value pointed out by Edlefson. In connection with simulated rainfall-type infiltration studies, the Infiltration Subcommittee of the U. S. D. A. Flood Control Coordinating Committee recognized the need for an extended test. In a memorandum of July 28, 1939, this committee issued "Instructions for Infiltration Surveys," which contained, in part:

> Readings should be taken every thirty seconds until the run-off approaches a constant value, then every one minute for about five minutes and finally every five minutes until it is definitely established that the run-off is constant or nearly so. This will require runs of from thirty minutes, which will be the minimum run under any conditions, to around two hours or more for dry relatively permeable soils. The average run is estimated to be about thirty minutes * * * Before starting the succeeding runs, sufficient time should be allowed for the soil moisture to reach equilibrium and to permit normal soil swelling. This will ordinarily require about twenty-four hours, consequently this is taken as the minimum time interval between runs * * * Ordinarily two runs, one at the existing soil moisture, and one no less than 24 hours later will be required for each plot. However, on the first plot of each strata sampled, additional runs should be made, also at no less than 24-hour intervals, to make certain that minimum infiltration rates are obtained. In some cases it may be necessary to make four or five runs to determine this rate.

Musgrave (10, 11) in developing and using the tube method for obtaining infiltration values points out that, for the purpose of determining erosion control practices, the interest lies primarily in minimum rates. The Musgrave tube method involves jacking a tube 6 to 9 inches in diameter and 18 to 24 inches long into the soil, leaving 2 or 3 inches protruding above the surface. A head of approximately one-fourth inch of water is maintained on the soil surface enclosed by the tube during the test. The volume of water required to maintain the head is measured at frequent intervals. An initial test is generally made at the prevailing soil moisture content and continued for about three hours, and a succeeding test is made on the same unit 24 hours later. Working with one soil type, Musgrave indicated that an initial run would have to be continued for approximately 24 hours in order to approach the same minimum rate obtained from a combination of initial and wet runs. He observed a relatively fast decline in rate for the first five hours and a slow decline for the remainder of the 24 hours.

Free, Browning, and Musgrave (12) report a study of infiltration characteristics of a wide variety of soils over the United States using the tube infiltration method. Tests were made at 68 sites, representing 39 soil series in 6 of the 12 great soil groups in the United States. They also represent a variety of parent materials and a rather complete range of soil textures from sands through clays. Soils were tested in 10 of the 48 States, representing a wide range of climatic conditions in the country. Tests extended over all seasons of the year. The wide range of soils was chosen so that relationships found for the group of soils studied might reasonably be expected to be generally true for other soils.

Twenty-four replicate infiltration tests were made at each site. An initial determination of infiltration rates was made at field moisture prevailing at the time. A succeeding determination was made 24 hours later, which is referred to as the wet run. Each testing period continued for 3 hours.

The initial runs almost invariably gave faster rates than the wet runs. The mean of the initial run third hour rates was 1.34 in./hr., while the mean of the wet run third hour rates was 0.88 in./hr., about a 34 percent reduction.

From the Free, et al. (12) data, the percent change in infiltration rates that took place between the third hour of the initial run and the third hour of the wet run has been calculated. Of the 68 sites, 65 had rates on which this comparison could be made. Of the 65 sites, 31 had rates faster than 1.0 in./hr., which is the generally accepted minimum rate soil absorption systems. The frequency distribution of rate changes is presented in table 35. In a large majority of the soils, the 2-day test was necessary in order to approach equilibrium rates. Considering the 65 soils, wet run rates for 56 of them, or 86 percent, were lower than initial run rates. Thirty-one of the soils, or 48 percent, showed a reduction in rate of 50 percent or greater.

TABLE 35.—Frequency distribution of rate changes from initial to wet run infiltration tests

Change of rate from 3d hour initial to 3d hour wet run (percent)	Frequency	
	All sites	Sites with rates >1.0 in./hr.
+40 to +1	9	4
0 to −9	3	0
−10 to −19	4	3
−20 to −29	5	3
−30 to −39	8	4
−40 to −49	5	5
−50 to −59	9	4
−60 to −69	12	5
−70 to −79	7	3
−80 to −89	2	0
−90 to −99	1	0
	65	31

If we consider only the 31 soils having wet run infiltration rates greater than 1.0 in./hr., 27 of them, or 87 percent, showed a reduction in rate for the wet run. Twelve of these soils, or about 39 percent, had a reduction of 50 percent or greater.

Musgrave points out that, because of the wide diversity of the soils in his study, the relationships found for this group of soils might reasonably be expected to be found generally for other soils. Thus, we might conclude that most of the soils in the country would require a two-day infiltration test in order to approximate equilibrium infiltration rates.

PERCOLATION METHODS

Methods of measuring the rate of water absorption or transmission by subsoils are generally referred to as permeability or percolation methods. Most of the percolation test methods in use, whether field or laboratory methods, provide some means of thoroughly saturating the soil and allowing it to swell before rates are measured.

Field Tests.—Percolation tests made in place are often conducted on an initial and wet run pattern similar to infiltration tests. One such method is used by the Bureau of Reclamation (13). An initial 6-hour run is followed two days later by a second 6-hour run. The Bureau of Reclamation manual states that, "This gives a percolation rate at prevailing field moisture conditions, and after the soil has been thoroughly wet and has had a 40-hour period to swell."

Vanatta and Uhland (14) used a similar method in determining percolation rates for soil classification purposes. They state that, "Tests were made through an 8-hour period . . . during normal to dry periods, the first 4-hour run made in the afternoon, and the second 4-hour run made the following morning. This procedure gives opportunity for colloidal swelling overnight. During normal to wet periods, the entire 8-hour run is usually made through 1 day." Calculations on soil permeability were made using data from the second 4-hour run. Triplicate percolation tests were conducted in holes 4 inches in diameter at 5 soil depths, 6, 12, 18, 24, and 30 inches, representing textures ranging from silt loam to clay. From the Vanatta and Uhland data, supplemented with unpublished data, it was computed that in 14 of 16 tests conducted with overnight saturation, percolation rates on the second day were at least 15 percent slower than on the first day. In 8 of the 15 tests, second day rates were about 50 percent slower. When the tests were made during an 8-hour period in 1 day, the rates tended to decrease rapidly during the first 4 hours and at a less rapid rate for the remaining time. However, in 14 out of 25 such tests the rate at the end of 8 hours was at least 20 percent slower than at the end of the first 4 hours. Thus, the need for prolonged testing or overnight saturation in order to obtain equilibrium percolation rates is apparent.

Laboratory Tests.—Precautions are also taken to insure complete saturation and swelling in percolation tests using soil cores. In one of the earlier laboratory investigations of soil percolation, Slater (15) adopted a procedure of taking percolation rates of natural cores on the second day of continued testing as a basis for comparing soils. "By so doing," he states, "a saturated condition was obtained for all of the cores." Laboratory packed cores were saturated by immersion in water overnight or longer. "This procedure," he points out, "not only saturated the soil by upward displacement of air, but produced slaking, shrinking, or swelling, and such other alterations as are analogous to the changes that take place when dry soil is saturated by rainfall in the field." Most recent investigators have used similar procedures in attempting to arrive at rates indicative for anticipated problems.

Continued Studies of the Percolation Tests, Effect of Hole Size, Saturation, Swelling

INTRODUCTION

The percolation test, as a tool for estimating the capacity of a soil for absorbing septic tank effluent, was developed by Henry Ryon (16, 17). Present percolation test methods recommended by most control agencies evidently developed from Ryon's original work. As written, most of these procedures involve the personal judgment of the operator. A need for a fundamental and objective percolation test is apparent; it is desirable to eliminate, for example, personal judgment as to what is considered "wet the soil," "equilibrium rate," "constant rate," etc. Such a test is highly desirable in instances where no testing experience is available. As experience is gained, a fundamental test may be used to develop modified or shortcut methods to meet local conditions.

Four modifications of present tests were suggested in the Part II report, page 48, as follows: (1) Use a smaller bored hole in place of the 1-foot-square dug hole; (2) use a more specific procedure to insure soil saturation, i. e., soak the soil overnight before making test; (3) use the percolation rate over the later period of the test, rather than an average rate, as being more nearly the true rate; (4) use several replicate tests in any area under consideration. Further studies, on a variety of soil types, are reported here. The primary purpose of the study was to investigate the influence of size and shape of test hole and the condition of soil saturation on measured percolation rates.

SOIL

Three different soils, namely, Genesee, Rossmoyne, and Brookston, were selected to represent a wide range of absorption rates and soil swelling characteristics, yet be representative of soils in which absorption systems have been installed. The physical characteristics of these soils in which the study was made are given in table 36.

The Genesee represents a large group of soils, typical of those found on stream terraces. They tend to have massive or weakly developed fragmental structure, and exhibit very little shrinking and swelling. The absorption capacity of this type of soil is usually favorable.

The Rossmoyne is a somewhat heavier-textured soil than the Genesee. It has a massive type of structure, in that aggregates cannot be distinguished as individual units. This type of soil is generally poorly drained and remains wet most of the time; consequently, it is usually in a swelled condition and should not exhibit much swelling during a percolation test. These soils tend to be slowly permeable to impermeable, and are unfavorable for soil absorption systems.

The Brookston is a heavy clay-type soil with well-developed blocky structure, rather stable to slaking by water. This soil exhibits a wide range of shrinking and swelling, and can be expected to show a wide variation in percolation rates with varying soil moisture conditions. Brookston represents a large group of soils in the United States.

PROCEDURE

Three sizes of test holes were included in the study: namely, a 12-inch-square dug hole, and 8-inch and 4-inch-diameter auger holes. Each size hole was installed in triplicate at each soil area studied. The holes were installed by random selection at the intersections of a 2-foot grid system in a 16-square-foot area. All holes were dug to an 18-inch depth.

After digging the holes, the bottoms and sides were scarified with a sharp-pointed rod to remove smeared surfaces, and all loose material was carefully removed. Two inches of pea gravel were then placed in each hole, and the holes were filled with water to a depth of 12 inches over the gravel. City tapwater was used in all of the tests. Water temperature ranged from 75° to 80° F.

As soon as the water was added, water-level measurements were started and continued at 10- to 15-minute intervals over a 2- to 4-hour period, refilling the holes to 12 inches over the gravel as necessary. This period will be referred to as the dry run. At the end of the day, the holes were filled with water and left to soak overnight. The following day, the holes were refilled with 12

TABLE 36.—**Physical characteristics of soils in which percolation test modification studies were made**

Soil name	Texture [1]				Structure [2]	
	Sand	Silt	Clay	Classification	Water stability	Classification
	Percent	*Percent*	*Percent*		*Percent*	
Genesee	33	41	26	Loam	23. 3	Massive.
Rossmoyne	25	38	37	Clay loam	28. 8	Do.
Brookston	24	35	41	Clay	49. 5	Blocky.

[1] Based on the Hydrometer Method (18) and the U. S. D. A. classification system (19).
[2] Based on Bryant's water-stability method (20) and classification system described by Baver (19).

inches of water and the fall in water-level measurements continued over a 4-hour period. This period will be referred to as the wet run.

The drops in water level for each test hole were plotted against elapsed time. Smooth curves were fitted to the data. From these curves, percolation rates were calculated. Rates for each day were calculated in two ways: (1) the average rate for each day; i. e., the total fall in water level divided by the time in hours, and (2) the rate over the last 30-minute period of each day; i. e., the drop divided by time in hours (0.5), which, for convenience, is referred to as the equilibrium rate.

RESULTS

The percolation rates for each test hole are presented in tables 37, 38, and 39. The data show that there is very little difference in the percolation rates measured in the different sized holes in the same soil. For instance, in the Brookston soil, table 37, averages of the 12 rates for each hole size are 12.9, 11.1, and 10.3 in./hr. for the 12-, 8-, and 4-inch holes, respectively; in the Genesee soil, table 38, the comparative rates are 7.5, 8.4, and 8.0 in./hr.; and in the Rossmoyne soil, table 39, the comparative rates are 0.7, 0.8, and 1.1 in./hr. The differences are all small, and there appears to be no overall correlation between percolation rate and size of hole. In the case of the Brookston, the smaller holes gave slightly slower rates; in the Rossmoyne, slightly faster rates; and in the Genesee no uniform trend. If the rates in the different sized holes are compared on the same type of run or the same type of rate, the averages are equally similar. Actually, it appears that the differences in rates between replicate tests within the same soils are greater than the differences in average rates between different sized holes in the same soils.

There does appear to be a difference between the dry run rates and the wet run rates for these soils. In the Brookston and Rossmoyne soils, the wet run rates average less than 50 percent of the dry run rates. 15.9 compared to 7.0 in./hr. for the Brookston, and 1.3 to 0.5 for the Rossmoyne. There was only a slight difference between the dry and wet runs in the Genesee soil.

A statistical analysis of variance of the data verifies the trends indicated by cursory examination of the data. The analysis also shows the relative significance of the differences in rates due to the various modifications of the percolation test. The results of the analysis of variance are given in table 40. The data have been analyzed first with all of the soils combined, and then by considering the individual soils separately.

The F ratios indicate the relative magnitude or significance of the differences in rates due to the different sources of variation or, in other words, due to the modifications of the test. When all of the soils are considered together, there is, of course, a highly significant difference between the rates obtained in the different soils. The differences due to the different runs, wet or dry, are significant at the 1 percent level. Differences due to the different method of computing the rates, average, and equilibrium, are significant at the 5 percent level. The difference in rates due to the size of holes is strikingly insignificant. Actually, the difference in rates due to hole size is considerably less than the difference between replicate tests in the same soil or due to all of the uncontrolled factors combined. There was a significant difference due to interactions of the various factors, not shown in the combined analysis in table 40.

This is probably due to the fact that one of the soils had higher rates during the wet run than the dry run, while the other two soils showed the op-

TABLE 37.—Percolation rates (in inches per hour) obtained in Brookston soil with various modifications of the percolation test method

Size and shape of hole	12-inch square				8-inch round				4-inch round			
Type of run	Dry		Wet		Dry		Wet		Dry		Wet	
Type of rate	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium	Average-	Equilibrium	Average	Equilibrium	Average	Equilibrium
	19.5	18.0	8.2	6.2	15.5	9.6	6.5	5.6	17.5	14.4	7.6	6.2
	16.7	14.4	10.4	5.8	23.9	13.8	9.3	4.0	15.9	12.0	8.7	6.8
	20.5	18.0	9.9	7.4	17.7	12.6	8.5	6.0	13.8	12.0	4.8	4.0
Replicate mean	18.9	16.8	9.5	6.5	19.0	12.0	8.1	5.2	15.7	12.8	7.0	5.7
Type of hole mean	12.9				11.1				10.3			
Type of run mean									15.9		7.0	
Type of rate mean											13.1	9.8
Overall mean											11.4	

TABLE 38.—Percolation rates (in inches per hour) obtained in Genesee soil with various modifications of the percolation test method

Size and shape of hole	12-inch square				8-inch round				4-inch round			
Type of run	Dry		Wet		Dry		Wet		Dry		Wet	
Type of rate	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium
	10.2	7.6	13.0	11.0	8.4	7.6	8.6	6.4	8.4	6.2	5.4	4.4
	6.9	6.0	7.5	5.8	8.5	7.2	10.5	8.8	9.6	7.2	12.6	10.2
	6.4	4.6	6.2	4.4	7.8	5.8	11.4	9.8	9.0	6.7	9.0	7.3
Replicate mean	7.8	6.1	8.9	7.1	8.2	6.9	10.2	8.3	9.0	6.7	9.0	7.3
Type of hole mean	7.5				8.4				8.0			
Type of run mean									7.5		8.5	
Type of rate mean											8.9	7.1
Overall mean												8.0

TABLE 39.—Percolation rates (in inches per hour) obtained in Rossmoyne soil with various modifications of the percolation test method

Size and shape of hole	12-inch square				8-inch round				4-inch round			
Type of run	Dry		Wet		Dry		Wet		Dry		Wet	
Type of rate	Average	Equilibrium	Average	Equilibrium	Average	Equilibrium	Average-	Equilibrium	Average	Equilibrium	Average	Equilibrium
	1.6	1.2	0.6	0.4	1.6	1.0	0.9	0.4	2.6	1.2	0.9	0.4
	1.0	.8	.4	.3	1.7	.7	.7	.2	1.8	.6	.7	.2
	1.3	.6	.1	.1	1.3	.5	.5	.4	2.7	1.4	.7	.2
Replicate mean	1.3	.9	.4	.3	1.5	.7	.7	.3	2.3	1.1	.8	.3
Type of hole mean	0.7				0.8				1.1			
Type of run mean									1.3		0.5	
Type of rate mean											1.7	0.6
Overall mean												0.9

TABLE 40.—Analysis of variance of percolation test modification data

All soils combined

Source of variation	d/f [1]	Sum of squares	Mean square	F ratio
Soils	2	2, 083. 1	1, 041. 5	[2] 49. 3
Holes	2	5. 5	2. 8	. 1
Runs	1	228. 8	228. 8	10. 8
Rates	1	94. 4	94. 4	[3] 4. 5
Residual	29	613. 1	21. 1	------

By separate soils

Source of variation	d/f	Genesee			Brookston			Rossmoyne		
		Sum of squares	Mean square	F ratio	Sum of squares	Mean square	F ratio	Sum of squares	Mean square	F ratio
Holes	2	5. 06	2. 53	4. 5	43. 06	21. 53	4. 3	1. 10	0. 55	2. 1
Runs	1	9. 20	9. 20	[2] 16. 4	710. 22	710. 22	[2] 142. 6	6. 68	6. 68	[2] 25. 6
Rates	1	29. 16	29. 16	[2] 52. 0	93. 76	93. 76	[2] 18. 8	3. 07	3. 07	[3] 11. 8
Residual	7	3. 92	. 56	--------	34. 89	4. 98	--------	1. 84	. 26	--------

[1] Degrees of freedom.

[2] 1 percent level of significance.

[3] 5 percent level of significance.

posite effect. For this reason, an analysis of variance was run on each of the soils separately.

The separate analysis tells much the same story as the combined analysis. The differences due to size of hole are insignificant in all of the soils. The differences due to different methods of calculating rates, average, or equilibrium, are significant at the 1 percent level in all of the soils. The differences are all in the same direction, the equilibrium rate is slower in every case. The differences due to wet or dry run are also significant in every soil, but in one of the soils, the Genesee, the wet run rates are significantly faster, while in the other two soils it is slower. As pointed out before, the Genesee soil is a type that does not shrink or swell, so that no great reduction in rate after soaking should be expected, but it is surprising that the wet run is faster.

DISCUSSION

The need for developing an improved percolation test in order to obtain minimum percolation rates is apparent throughout the data. The practical significance of obtaining minimum rates may be illustrated by reference to table 41, in which the mean percolation rates obtained under the various test modifications are tabulated. The rates have been converted to units of minutes per inch in order to estimate absorption areas directly from the design table in the Recommendations of the Joint Committee on Rural Sanitation (21).

The method of carrying out the percolation test affects the estimate of the size of absorption field required. The Rossmoyne soil site, if judged on the basis of the average rate of the dry run, which may be considered comparable to the rate that would be obtained on this soil by a conventional test method, would be considered acceptable for an absorption field. Considering the rates obtained in the three different sized holes as replicates, the absorption area required for this soil would be 206 square feet per bedroom. If the soil were judged by the equilibrium rate of the dry run, or either of the wet run rates, it would be considered unacceptable for the conventional absorption field according to the design table. This latter judgment agrees with the performance of this soil under actual conditions. Of several systems observed in this type of soil, not one was operating satisfactorily. One system, inspected in detail, had approximately 300 square feet of absorption area in addition to a seepage pit at the end of one of the tile lines. The system received toilet wastes only, from a family of 1 adult and 2 children. At the time of the inspection, the system was in failure. The tile lines were surcharged, the seepage pit was full, and there was surface seepage over the entire field. This inspection was made during August, when temperatures were high, vegetation was lush, and the surrounding soil was comparatively dry. Such conditions should be the most favorable for successful operation of an absorption field, and yet this system was a failure. From these observations, it is obvious that the equilibrium wet run rate gives the most accurate picture of what can be expected of an absorption field in the Rossmoyne soil.

TABLE 41.—Effect of modifications of the percolation test method on measured percolation rates and the estimated soil absorption area required for 3 soils

Soil and size of hole	Dry run						Wet run					
	Average rate			Equilibrium rate			Average rate			Equilibrium rate		
	In./hr.	Min./in.	Area[1] required sq. ft./B. R.	In./hr.	Min./in.	Area[1] required sq. ft./B. R.	In./hr.	Min./in.	Area[1] required sq. ft./B. R.	In./hr.	Min./in.	Area[1] required sq. ft./B. R.
Rossmoyne:												
4" round	2. 3	26	182	1. 1	54	232	0. 8	75	N. G.	0. 3	200	[2] N. G.
8" round	1. 5	40	214	. 7	85	[2] N. G.	. 7	85	N. G.	. 3	200	N. G.
12" square	1. 3	46	222	. 9	66	N. G.	. 4	150	N. G.	. 3	200	N. G.
Mean	-----	-----	-----	-----	-----	N. G.	-----	-----	N. G.	-----	-----	N. G.
Genesee:												
4" round	9. 0	7	88	6. 7	9	96	9. 0	7	88	7. 3	8	92
8" round	8. 2	7	88	6. 9	9	96	10. 2	6	84	8. 3	7	88
12" square	7. 8	8	92	6. 1	10	100	8. 9	6	84	7. 1	8	92
Mean	-----	-----	89	-----	-----	97	-----	-----	86	-----	-----	91
Brookston:												
4" round	15. 7	4	70	12. 8	5	80	7. 0	9	96	5. 7	10	100
8" round	19. 0	3	60	12. 0	5	80	8. 1	8	92	5. 2	10	100
12" square	18. 9	3	60	16. 8	4	70	9. 5	6	84	6. 5	9	98
Mean	-----	-----	63	-----	-----	77	-----	-----	91	-----	-----	99

[1] Interpolated from the Recommendations of Joint Committee on Rural Sanitation (21).

[2] N. G.—Soil not acceptable for absorption field.

In the Genesee soil, all rates were more nearly the same. If judged on the basis of the equilibrium rates, this soil would require only slightly larger absorption areas. In all probability, the differences are small because of the nonswelling characteristics of this soil. Consequently, this particular soil may not require rigid saturation procedures.

The Brookston soil offers a striking example of how the percolation test modifications can affect the measured rates to a practical extent. The absorption area required, as judged by the average dry run rate, would be 63 square feet, while, if judged on the equilibrium wet run rate, it would be 99 square feet, or 60 percent larger. The slower rate is undoubtedly more representative of this soil under the conditions of saturation in a tile field. A system designed on the equilibrium wet run rate basis is much more likely to operate successfully the year around.

Brookston is typical of a large group of soils, in its shrinking and swelling characteristics. Similar soils may be found in most parts of the United States. As this soil dries out, the structural units shrink and numerous cracks develop, allowing a very fast initial absorption rate. As the units swell, the cracks close, and the absorption rate decreases, finally approaching a minimum.

It is not practical to attempt to measure the absolute minimum rate for any soil by a prolonged test, as the rate may continue to decrease over a long period of time. However, it is practical and advisable to obtain a measured rate that is beyond the point of rapid change in the rate-time curve. This can be illustrated by reference to plate 18, in which percolation rates for both the dry and the wet run tests in a Rossmoyne soil are plotted. It will be noted in both curves that during the first 2 hours of the test the percolation rates were rapidly decreasing. From the 2-hour point on, the decrease in rate was less rapid.

It may also be noted from these curves that the soil moisture conditions prior to the test had tremendous effect on the initial rates. The dry run was started with the soil at its natural field moisture content, which was rather low. The wet run was made the next day after the test hole had been filled with water for most of the overnight period between the two runs. The initial rates of the two runs reflect these different moisture conditions. The rates of the dry run were higher at the start and decreased more rapidly.

These studies were all made within a narrow temperature range of from 75° to 80° F., so that any effect due to temperature variations was considered minor. Theoretically, the temperature of the soil and water during the test affect viscosity, and might be expected to have some effect on percolation. Studies by others (12, 22) have shown that this is true, but the effect is small over the temperature range from near freezing to about 100° F. As compared to the other uncontrollable factors, it is generally considered negligible in practical field tests.

EFFECT OF SOIL VARIABILITY

The need for making replicate tests in any soil area under consideration was pointed out in a previous report (2). Further evidence was obtained in a tile field study in Nashville, Tenn. In this study 24 percolation tests were spaced uniformly over an area 300 by 30 feet, in two adjacent tile fields under construction. The tests were made in the bottom of the open trenches by the confined tube method. A 4-inch diameter cylinder was carefully driven 3 inches into the soil in the trench bottom, and the test was conducted in the same manner as previously described for auger holes. A plot layout of the area and the equilibrium percolation rates obtained at each test site are shown in plate 19. These data demonstrate quite strikingly the variability in absorption capacity of soils that can be encountered in relatively small areas. It will be noted in the diagram that the center of the rectanglar area, which is separated by the dashed lines, is considerably more permeable than the soil at the outer ends of the area. The percolation rates varied from 4 inches per hour (15 minutes per inch) to less than 1 inch per hour (greater than 60 minutes per inch). On the basis of Joint Committee design tables (21), this soil varies from one that is definitely unacceptable to one that is rather porous. Without replication of tests in this area, this variability might not be noted.

Statistical studies made by Free et al. (12), indicated that from 6 to as many as 22 individual infiltration tests are necessary to estimate closely the representative rate for a specific soil site. This replication is presumably necessary to take into account only the variability of relatively homogeneous soils. When the soils themselves vary in absorption capacity, the number of tests needed may be larger, but a minimum of 6 tests in an area should at least delineate any such differences.

EFFECT OF OTHER SOIL CONDITIONS

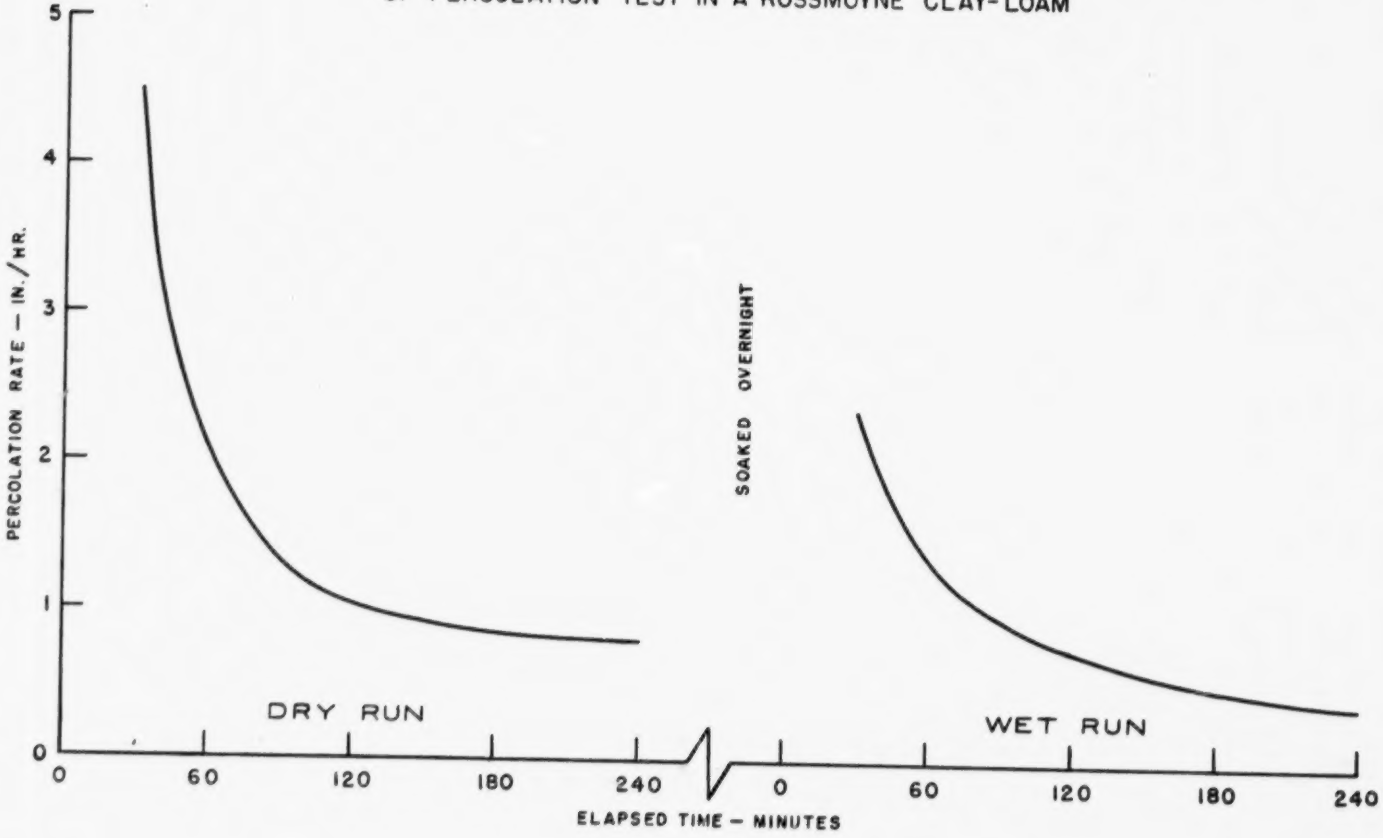
Although we may adopt techniques in an attempt to reflect soil moisture conditions as they might be during absorption field operation, the extent to which we can do this is limited. One of the most difficult soil conditions to evaluate is the effect of relatively shallow impermeable soil layers. In some cases, rock, hardpans, or claypans at a shallow depth may not influence the percolation test, but may affect the operation of an absorption field where the area must absorb large volumes of water over an extended time period.

Another condition that may not be reflected by a percolation test, but which may influence soil absorption systems, is the presence of ground water at relatively shallow depths below a test hole or below absorption trenches. The limited volume of water applied during the test may have no influence on raising the water table and, thus, affecting the measured rates. On the other hand, absorption systems, particularly where there is a concentration of systems, may add enough water to cause a shallow water table to rise locally and interfere with the systems. If more water is put into the soil than leaves through percolation or evapotranspiration, water will be stored in the ground and the water table will rise. As the water table rises, its slope becomes steeper and the rate of movement of water laterally from the area becomes greater. However, if the lateral flow is still not great enough to balance the inflow, further rise in the ground water may result in surface seepage.

These conditions are not uncommon. The percolation tests should, therefore, be supplemented with inspection of the soil profile by auger borings to detect such conditions. If such conditions are noted, then results of percolation tests should be applied with caution. In this respect, each system or group of systems in a small area is an individual problem, and must be judged by its own peculiar conditions of hardpan, water table, topography, etc. However, as a guide, Kiker (23) has suggested that there should be a minimum depth of

PLATE 18

PERCOLATION RATES DURING DRY AND WET RUNS OF PERCOLATION TEST IN A ROSSMOYNE CLAY-LOAM



4 feet of permeable soil overlying any impermeable layer or overlying the ground water table.

Consideration of evaporation phenomena and capillary rise from shallow ground water (24) would lend support to a minimum depth of approximately 4 feet. Current studies may shed further light on this subject. In consideration of the above, a soil should not only have an acceptable percolation rate, but there should also be adequate depth of permeable soil overlying subsurface obstructions.

FITTING OF EQUATIONS TO PERCOLATION TEST DATA

It would be very desirable to develop a shortcut percolation test or be able to extrapolate an equilibrium percolation rate from a minimum amount of data. A number of attempts to do this have been made for specific conditions. Kiker (25) in Florida, and Ludwig et al. (26, 27) in California, for instance, have developed equations applicable to their conditions.

Free, Browning, and Musgrave (12) have shown in a study of infiltration rates, which may be considered comparable to percolation rates determined on surface soils, that the relation between time and infiltration, either on a cumulative or a rate basis, is curvilinear. Their studies included 68 soils located all over the country. From a study of these soils, the authors concluded that the relation may be represented by an equation of the general form: $I=bt^a$, where I is the cumulative infiltration in inches, t is the elapsed time of the test in minutes, and b and a are constants that vary with soils, prior moisture conditions, etc. In the soils studied, the constant b varied from unity to 0.0087, and the exponent a from 0.04 to 0.82. It will be noted that the infiltration rate does not become constant except when $a=1$, but for practical purposes the rate approaches a constant with large values of t.

In formulating percolation test rates, one should keep in mind that equilibrium rates develop only after soil swelling is essentially complete. Consequently, the proper development and application of formulae do not necessarily imply short tests.

PERCOLATION TEST PROCEDURE

Because of the great number of factors that may affect a percolation test and the variability that can be expected in the rate-time relationship, it appears unlikely that a short-time procedure can be developed, applicable to all soils and all conditions.

It is thought best at this time to concentrate on developing a fundamental and objective test procedure which can be applied to a wide range of soils and which, as has been pointed out, would be essential in clay-type soils. Such a test would also be essential where no experience with test methods or a particular soil is available. As experience is gained, the test might be modified to suit local conditions. The fundamental test might also be used to check modified procedures from time to time.

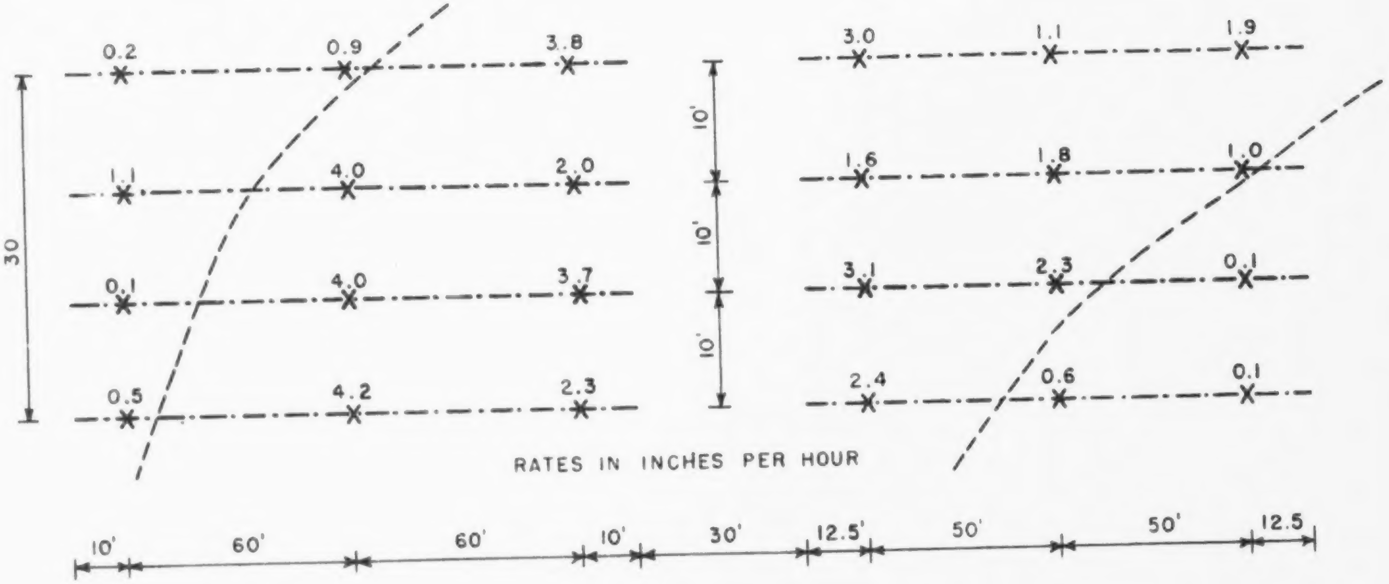
The following percolation test is suggested as a fundamental and objective procedure:

1. *Number and location of tests.*—Six or more tests shall be made in separate test holes spaced uniformly over the proposed absorption field site.
2. *Type of test hole.*—Dig or bore a hole, with horizontal dimensions of from 4 to 12 inches and vertical sides, to the depth of the proposed absorption trench. In order to save time, labor, and volume of water required per test, the holes can be bored with a 4-inch auger.
3. *Preparation of test hole.*—Carefully scratch the bottom and sides of the hole with a knife blade or sharp pointed instrument, in order to remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Remove all loose material from the hole. Add 2 inches of coarse sand or fine gravel to protect the bottom from scouring and sediment.
4. *Saturation and swelling of the soil.*—Carefully fill the hole with clear water to a minimum depth of 12 inches over the gravel. By refilling if necessary, or by supplying a surplus reservoir of water, such as in an automatic siphon, keep water in the hole for at least 4 hours and preferably overnight. Allow the soil to swell overnight. This saturation procedure insures that the soil is given the opportunity to swell and approach the condition that it will be in during the wettest season of the year. Thus, the test will give comparable results in the same soil whether made in a dry or a wet season.

In sandy soils containing little or no clay, the swelling procedure is not essential and the test may be made as described under item 5C, after the water from one filling of the hole has completely seeped away.

PLATE 19

VARIABILITY IN SOIL AS SHOWN BY PERCOLATION RATES MEASURED IN ONE ABSORPTION FIELD AREA


0.2
0.9
3.8
3.0
1.1
1.9
1.1
4.0
2.0
1.6
1.8
1.0
0.1
4.0
3.7
3.1
2.3
0.1
0.5
4.2
2.3
2.4
0.6
0.1
30
10'
10'
10'
RATES IN INCHES PER HOUR
10'
60'
60'
10'
30'
12.5'
50'
50'
12.5

5. *Percolation rate measurement.*—With the exception of sandy soils, percolation rate measurements shall be made on the day following the procedure described under item 4, above.

A. If water remains in the test hole after the overnight swelling period, adjust the depth to approximately 6 inches over the gravel. From a fixed reference point, measure the drop in water level over a 30-minute period. This drop is used to calculate the percolation rate.

B. If no water remains in the hole after the overnight swelling period, add clear water to bring the depth of water in the hole to approximately 6 inches over the gravel. From a fixed reference point, measure the drop in water level at approximately 30-minute intervals for 4 hours, refilling 6 inches over the gravel as necessary. The drop that occurs during the final 30-minute period is used to calculate the percolation rate. The drops during prior periods provide information for possible modification of the procedure to suit local circumstances.

C. In sandy soils (or other soils in which the first 6 inches of water seeps away in less than 30 minutes, after the overnight swelling period) the time interval between measurements shall be taken as 10 minutes and the test run for 1 hour. The drop that occurs during the final 10 minutes is used to calculate the percolation rate.

6. *Additional criteria for judging soil suitability.*—In areas of shallow ground water, the depth to the water table shall be determined. If, for any extended period during the year, the water table is normally at a depth of less than 4 feet, the results of the percolation test should be applied with caution. The case also warrants special consideration if impermeable layers are found at depths of less than 4 feet.

PERCOLATION RATE AND ALLOWABLE SEWAGE LOADING

The percolation rate-allowable sewage loading rate relationship, upon which most current design area tables are apparently based, was developed by Ryon (16, 17). In conducting percolation tests, Ryon (88) recognized and emphasized the necessity of having the soil thoroughly wet before measuring percolation rates. It is judged from this that Ryon used a critical procedure approaching or equaling the complete saturation and soil swelling suggested in this report. Thus, it is thought that rates obtained with the suggested test are reasonably applicable to the original Ryon loading relationship. This is not necessarily true of many current percolation test procedures which involve personal judgment. In such cases, the suggested fundamental test may give slower, but more representative, rates.

Changes in sewage characteristics since Ryon's original work may have altered the relationship to the extent that new relationships and design area tables may be desirable. Also, as indicated in Section I, page 118, climatic factors may influence the relationship so that it may be advantageous to develop relationships on a climatic region basis.

Taking into account recent water-consumption data, effects of garbage-grinders and automatic sequence washers, the original Ryon allowable sewage loading data (17), and additional data on clogged systems (2), and utilizing modern statistical approaches, the following design area table has been developed.

Percolation rate (time required for water to fall 1 inch—in minutes)	Required absorption area (square feet of absorption trench bottom per bedroom)			
	Without garbage-grinder or automatic washer [1]	With garbage-grinder [2]	With automatic washer [3]	With both garbage grinder and automatic washer [4]
2 or less	50	65	75	85
3	60	75	85	100
4	70	85	95	115
5	75	90	105	125
10	100	120	135	165
15	115	140	160	190
30	150	180	205	250
45	180	215	245	300
60	200	240	275	330
Over 60	Unsuitable for shallow absorption system. Investigate for seepage pit or subsurface filter arrangement.			

Note.—The above areas are the estimated 99 percentile or higher, values (rounded), calculated by statistically combining the following factors:

[1] Allowable sewage loading values for each percolation rate, derived from Ryon (16, 17) and P. H. S. (2) data, with winter water consumption and home occupancy values from this report.

[2] Factors noted above, with garbage area increases derived from soil core data in this report.

[3] Factors noted in 1 above, with increase in water consumption in automatic sequence washer-equipped homes, as indicated in this report.

[4] Factors noted in 1, 2, and 3 above.

SECTION E

Further Studies on Clogging Characteristics of Septic Tank Effluent

INTRODUCTION

The characteristics of septic tank effluent which may affect soil clogging, as pointed out in a previous report (2), can be considered as physical, chemical, and biological.

Physical clogging is simply the plugging of soil pores by solid particles strained from effluent as it percolates into the soil. It has long been assumed that this type of clogging, under field conditions, is one of the more important factors. One of the primary functions of a septic tank is to remove as many of the suspended solids as possible from the sewage to reduce physical soil clogging. Preliminary studies (2) have confirmed this assumption. Clogging of soil cores was found to be directly related to the amount of suspended solids in the effluent applied, the greater the solids the greater the clogging.

Although the chemical and biological factors are not so obvious in their effects, both can affect absorption field behavior. In agriculture, both types of clogging have long been a problem. The chemical quality of irrigation waters must be carefully controlled to prevent damage to soil absorption properties through deterioration of soil structure. Biological activity likewise has been observed to cause a decrease in water absorption capacities of soils (29). However, in studies described in an earlier report (2), the net effect of biological activity in soil cores dosed with effluent seemed to be beneficial from the clogging viewpoint. Studies to define further the characteristics of effluent which influence soil clogging have been continued. Four series of laboratory studies and one series of field auger hole studies are reported here.

Laboratory Studies

PREPARATION OF SOIL CORES, DOSING, SAMPLING

Due to difficulties encountered in obtaining representative undisturbed soil cores, all laboratory studies were made on soil cores manually packed with disturbed soil. Soils were collected from selected areas at a depth at which absorption trenches would normally be installed. Sufficient soil was collected at each site to represent average conditions. The soils were partially air dried by spreading thinly on canvases. When the soil was sufficiently dry to work, at a moisture content where it would not smear or puddle, the lumps were gently broken sufficiently to pass a No. 6 sieve. The sieved soil was then packed into core cylinders by the procedure outlined in an earlier report (2). By controlling the number of roddings, tampings, and moisture content, different degrees of packing could be obtained. For any one series of cores, this factor was kept constant. The surface was covered with a 1-inch layer of washed pea gravel, and the cylinders were sealed into the funnels with paraffin.

The soil cores were saturated from below by immersing in water and gradually raising the water level in an immersion tank. The saturated cores were removed to racks for dosing treatment, where they were dosed with tapwater until a representative rate for each core was reached. The cores were then ready for effluent dosing treatments prescribed by the study.

During dosing, enough septic tank effluent was added daily to replace the effluent that passed through the core in the previous 24 hours. A liquid head maintained on the cores at all times fluctuated between ¼ inch and 3 inches. Daily percolation rates were calculated. Solids analyses of applied effluent were made daily. Special determinations were made as needed.

Series 1—Genesee Soils—Biological and Chemical Factors

DESCRIPTION, PROCEDURES

Studies under Series 1 were designed primarily to investigate the biological and chemical factors. The soils used are representative of alluvial soils in the Ohio River Valley occurring along stream terraces, and are classed in the Genesee series (35). One was a Genesee silt loam composed of 23, 49, and 28 percent sand, silt, and clay, respectively, having a weakly developed angular structure. It was rather permeable, in situ, having a percolation rate of approximately 8 inches per hour. The other was a Genesee loam composed of 32, 46, and 22 percent sand, silt, and clay, respectively, having no developed structure, and was less permeable than the Genesee silt loam.

Twenty-four cores of each soil were dosed for about three months. The dosing solutions were effluent from a septic tank receiving normal sewage, effluent from a tank receiving ground garbage in addition to sewage, filtered raw sewage, and tapwater. Some of the dosing solutions were disinfected to minimize the effect of biologic activity, and some were fortified with calcium to vary chemical characteristics. The detailed dosing plans are included in tables 42 and 43.

When dosing was completed, biologic activity in the top inch and bottom inch of the cores under each treatment was determined by bacterial plate counts on composite samples. It is apparent from the counts in table 42 that at least a partial disinfection was obtained. For both of the soil types, plate counts on the soil receiving disinfected treatments tend to be lower than those on the soils receiving normal treatments. Disinfection of the soil was practically 100 percent effective on the tapwater treatments.

TABLE 42.—Bacterial plate counts [1] on soils dosed with disinfected effluents as compared to normal effluents

Soil type and sample location	Soil core dosing treatment											
	Sewage effluent				Sewage garbage effluent				Tapwater			
	Normal		Disinfected		Normal		Disinfected		Normal		Disinfected	
	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca
Genesee silt loam:												
Top 1 inch of core	77	54	67	5	87	93	41	32	57	36	0. 05	0. 02
Bottom 1 inch of core	80	97	44	52	3, 667	116	64	121	118	41	. 04	Neg.
Genesee loam:												
Top 1 inch of core	28	10	45	1	44	20	5	47	194	......	. 002	......
Bottom 1 inch of core	92	128	5	4	85	64	17	26	69	......	Neg.	......

[1] Plate counts made on nutrient agar incubated at 37° C. for 24 hours expressed as colonies × 10^4/gm. of soil.

RESULTS, DISCUSSION

The condensed results from this series of cores are given in tables 43 and 44. The percolation rates tabulated for individual cores are the rate values taken from curves fitted to the basic data. The rate values are given at critical points in the dosing schedule; i. e., the start, end, and after 1.0 gm. of suspended solids had been added. The rate trends were similar to those shown in an earlier report (2).

Biological-Type Clogging.—In practically all cases, the disinfected effluents caused more clogging, that is, reached lower percolation rates. The data of tables 43 and 44 have been rearranged, according to disinfection treatment, in table 45. The percolation rates of all of the effluent cores at the start of the test are quite comparable; actually there is no significant difference between the rates by an analysis of variance. The average of the percolation rates at the start of dosing for all of the cores treated with normal effluent is 14.02 cc./hr. as compared to 14.37 cc./hr. for the disinfected effluent treated cores. After 80 days of dosing, the respective average rates were 4.64 and 1.88 cc./hr. This difference is highly significant. The percolation rates of cores dosed with normal effluent were reduced to about 33 percent of the original rates, while those of the cores dosed with disinfected effluent were reduced to about 13 percent.

TABLE 43.—Results of various effluent dosing treatments on soil core percolation rates of Genesee loam

	Soil core dosing treatments											
	Sewage effluent [1]				Sewage + garbage effluent [2]				Tapwater			
	Normal		Disinfected [3]		Normal		Disinfected		Normal		Disinfected	
	− Ca	+ Ca [4]	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca
Percolation rate at start of core dosing—cc./hr.:												
Duplicate No. 1	15. 2	15. 4	15. 2	15. 2	16. 0	15. 2	14. 8	14. 6	15. 6	14. 1	18. 2	17. 9
Duplicate No. 2	12. 4	13. 4	15. 2	13. 2	12. 4	13. 3	14. 8	14. 6	12. 2	14. 1	12. 4	11. 8
Average	13. 8	14. 4	15. 2	14. 2	14. 2	14. 25	14. 8	14. 6	13. 9	14. 1	15. 3	14. 85
Percent	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
Percolation rate after 80 days of dosing—cc./hr.:												
Duplicate No. 1	5. 0	4. 7	. 9	1. 2	3. 9	3. 2	1. 2	1. 6	9. 2	17. 8	39. 0	49. 6
Duplicate No. 2	3. 9	4. 3	. 9	1. 0	3. 4	3. 7	1. 2	1. 9	5. 6	17. 8	13. 7	14. 6
Average	4. 45	4. 5	. 9	1. 1	3. 65	3. 5	1. 2	1. 75	7. 4	17. 8	26. 35	31. 8
Percent	32. 3	31. 3	5. 9	7. 8	25. 7	24. 8	8. 1	12. 0	53. 4	126. 2	172. 0	214. 0
Percolation rate after the accumulation of 1.0 gm. of suspended solids—cc./hr.:												
Duplicate No. 1	5. 5	5. 2	1. 1	1. 1	4. 5	3. 6	1. 3	1. 5	------	------	------	------
Duplicate No. 2	4. 1	4. 8	1. 0	1. 1	4. 1	4. 3	1. 3	1. 3	------	------	------	------
Average	4. 8	5. 0	1. 05	1. 1	4. 3	3. 95	1. 3	1. 4	------	------	------	------
Percent	34. 8	34. 8	6. 9	7. 8	30. 3	27. 7	8. 8	9. 6	------	------	------	------

[1] Sewage effluent obtained from tank 9A to which only sewage is added.

[2] Sewage + garbage effluent obtained from tank 5 to which ground garbage in addition to sewage is added.

[3] Disinfected by addition of 1,000 p. p. m. formaldehyde.

[4] Fortified with calcium by addition of 1,000 p. p. m. gypsum.

TABLE 44.—Results of various effluent dosing treatments on the soil core percolation rates of Genessee silt loam

	Soil core dosing treatments											
	Sewage effluent [1]				Sewage + garbage effluent [2]				Raw sewage [5]		Tap water	
	Normal		Disinfected [3]		Normal		Disinfected		Normal		Normal	Disinfected
	− Ca	+ Ca [4]	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca	− Ca	+ Ca
Percolation rate at start of core dosing—cc./hr.:												
Duplicate No. 1	18. 5	16. 1	18. 4	15. 7	16. 6	16. 2	16. 6	15. 7	16. 0	14. 8	7. 8	8. 7
Duplicate No. 2	9. 4	11. 1	10. 1	11. 7	10. 6	12. 5	10. 8	13. 3	12. 5	12. 9	7. 0	2. 8
Average	13. 95	13. 6	14. 25	13. 7	13. 6	14. 35	13. 7	14. 5	14. 25	13. 85	7. 4	5. 75
Percent	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0	100. 0
Percolation rate after 80 days of dosing—cc./hr.:												
Duplicate No. 1	6. 9	8. 5	1. 1	1. 7	3. 9	3. 8	4. 9	2. 4	2. 6	4. 2	2. 2	4. 4
Duplicate No. 2	3. 4	5. 9	5. 1	1. 6	3. 0	6. 8	2. 4	. 9	2. 0	5. 6	2. 0	. 8
Average	5. 15	7. 15	3. 1	1. 65	3. 45	5. 3	3. 65	1. 65	2. 3	4. 9	2. 1	4. 6
Percent	36. 9	52. 6	21. 8	12. 1	25. 4	37. 0	26. 6	11. 4	16. 2	35. 4	28. 4	80. 0
Percolation rate after accumulation of 1.0 gm of suspended solids—cc./hr.:												
Duplicate No. 1	9. 0	10. 3	4. 2	3. 5	5. 4	5. 5	8. 7	3. 5	3. 2	4. 9	------	------
Duplicate No. 2	3. 5	6. 2	5. 4	2. 0	3. 2	7. 1	1. 9	3. 0	3. 4	6. 6	------	------
Average	6. 25	8. 25	4. 8	2. 75	4. 3	6. 3	5. 8	3. 25	3. 3	5. 75	------	------
Percent	44. 8	60. 7	33. 7	20. 01	31. 6	44. 0	42. 3	22. 4	23. 2	41. 6	------	------

[1] Sewage effluent obtained from tank 9A to which only sewage is added.

[2] Sewage + garbage effluent obtained from tank 5 to which ground garbage in addition to sewage is added.

[3] Disinfected by addition of 1,000 p. p. m. formaldehyde.

[4] Fortified with calcium by addition of 1,000 p. p. m. gypsum.

[5] Fresh raw sewage filtered through a glass wool pad.

TABLE 45.—Comparative percolation rates of soil cores after being dosed with disinfected effluent and with normal effluent

	Percolation rate at start of core dosing				Percolation rate after dosing for 80 days				Percolation rate after the accumulation of 1.0 gm. of suspended solids	
	Effluent		Tapwater		Effluent		Tapwater		Effluent	
	Normal	Disinfected	Normal	Disinfected	Normal	Disinfected	Normal	Disinfected	Normal	Disinfected
	cc./hr.	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*
	15. 2	15. 2	15. 6	18. 2	5. 0	0. 9	9. 2	39. 0	5. 5	1. 1
	12. 4	15. 2	12. 2	12. 4	3. 9	. 9	5. 6	13. 7	4. 1	1. 0
	15. 4	15. 2	14. 1	17. 9	4. 7	1. 2	17. 8	49. 6	5. 2	1. 1
	13. 4	13. 2	14. 1	11. 8	4. 3	1. 0	17. 8	14. 6	4. 8	1. 1
	16. 0	14. 8	7. 8	8. 7	3. 9	1. 2	2. 2	4. 4	4. 5	1. 3
	12. 4	14. 8	7. 0	2. 8	3. 4	1. 2	2. 0	. 8	4. 1	1. 3
	15. 2	14. 6	--------	--------	3. 2	1. 6	--------	--------	3. 6	1. 5
	13. 3	14. 6	--------	--------	3. 7	1. 9	--------	--------	4. 3	1. 3
	18. 5	18. 4	--------	--------	6. 9	1. 1	--------	--------	9. 0	4. 2
	9. 4	10. 1	--------	--------	3. 4	5. 1	--------	--------	3. 5	5. 4
	16. 1	15. 7	--------	--------	8. 5	1. 7	--------	--------	10. 3	3. 5
	11. 1	11. 7	--------	--------	5. 9	1. 6	--------	--------	6. 2	2. 0
	16. 6	16. 6	--------	--------	3. 9	4. 9	--------	--------	5. 4	8. 7
	10. 6	10. 8	--------	--------	3. 0	2. 4	--------	--------	3. 2	1. 9
	16. 2	15. 7	--------	--------	3. 8	2. 4	--------	--------	5. 5	3. 5
	12. 5	13. 3	--------	--------	6. 8	. 9	--------	--------	7. 1	3. 0
Average	14. 02	14. 37	11. 80	11. 97	4. 64	1. 88	9. 10	20. 35	5. 39	2. 62

Variations in individual core rates result in differences in suspended solids added. As soil clogging is related to solids, further comparison of rates was made after cumulative addition of 1.0 gm. of suspended solids. Such a comparison should balance out the effect due to solids and indicate the net effect of disinfection. After this addition, the normal effluent core rates were reduced to 5.39 cc./hr., or about 39 percent of the original rates, while the disinfected effluent core rates were reduced to 2.62 cc./hr., or about 18 percent. Regardless of the method of comparison, reduction in biological activity resulted in greater clogging.

That the increase in clogging is not due to the formaldehyde, as such, is shown by the fact that with tapwater the addition of formaldehyde resulted in less clogging. In fact, the disinfected tapwater cores increased in rate all during the study.

Chemical-Type Clogging.—It has been found necessary to control carefully the chemical quality of irrigation water, in order to prevent damage to soil water absorption properties (36, 37). The ratio of sodium to the total base cations, calcium, magnesium, and sodium (called the sodium ratio), is considered the critical factor in water quality control. Waters in which 65 percent or more of the base cations are sodium may be considered of poor quality. Those between 50 and 65 percent are of doubtful quality, and those less than 50 percent are generally considered satisfactory (38). There are indications that potassium may have similar, but less pronounced, damaging effects (39). Due to the low concentrations of potassium generally found in irrigation waters, it has not received as much attention.

The mineral concentrations of sewage and of septic tank effluents depend upon the concentrations in the water supply and the contribution from the household. Wilcox (40) reports that, from a comparison of the composition of water supply and sewage effluent from several southern California sewage treatment plants (predominantly Imhoff tanks), the effluents are more concentrated than the input waters by at least twofold. He further says that the concentrations of boron, bicarbonate, and sodium in many of the effluents are disproportionately high. Incomplete partial mineral analyses of Cincinnati tapwater, sewage, and septic tank effluent confirm this trend for septic tank effluents. These trends suggest that the chemical quality of septic tank effluents may influence soil clogging. Therefore, a study of possible influence was undertaken.

The problem was attacked indirectly on the assumption that if the sodium ratio of a septic tank effluent is high enough to cause damage to soil absorption characteristics, the addition of calcium to the effluent should lower the ratio and prevent or reduce such damage.

In the two sets of Genesee soil cores in this series, reported in tables 43 and 44, some of the cores were dosed with effluents or tapwater to which calcium had been added, as 1,000 p. p. m. gypsum (232 p. p. m. Ca).

The data from tables 43 and 44 have been rearranged according to calcium treatment in table 46. The beneficial effect of the calcium addition to the tapwater dosing treatment is obvious. The average starting rates of the two groups of tapwater-dosed cores were 11.57 cc./hr. and 12.20 cc./hr., which are not significantly different. The respective average rates after 80 days of dosing were 17.50 cc./hr. and 11.95 cc./hr. with and without calcium, respectively, which are significantly different. In fact, a majority of the calcium cores had higher rates at the end of the dosing than at the start.

The overall effect of calcium added in the septic tank effluents is not so obvious. However, comparing tables 43 and 44, it is evident that the effect of calcium is different for the different soils. Considering the normal effluents, the effect of calcium appears to be definitely related to the soil type. With the Genesee loam, which has no developed structure, there appears to be no difference in the clogging: with the Genesee silt loam, which does have a weakly developed angular structure, the calcium fortified normal effluents tend to maintain higher percolation rates, that is, cause less clogging.

TABLE 46.—Comparative percolation rates of soil cores dosed with calcium fortified effluent and natural effluent

	Percolation rate at start of core dosing				Percolation rate after dosing for 80 days				Percolation rate after the accumulation of 1.0 gm. suspended solids	
	Effluent		Tapwater		Effluent		Tapwater		Effluent	
	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca	−Ca	+Ca
	cc./hr.	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*	*cc./hr.*
	18. 5	16. 1	7. 8	8. 7	6. 9	8. 5	2. 2	4. 4	9. 0	10. 3
	9. 4	11. 1	7. 0	2. 8	3. 4	5. 9	2. 0	0. 8	3. 5	6. 2
	18. 4	15. 7	15. 6	14. 1	1. 1	1. 7	9. 2	17. 8	4. 2	3. 5
	10. 1	11. 7	12. 2	14. 1	5. 1	1. 6	5. 6	17. 8	5. 4	2. 0
	16. 6	16. 2	18. 2	17. 9	3. 9	3. 8	39. 0	49. 6	5. 4	5. 5
	10. 6	12. 5	12. 4	11. 8	3. 0	6. 8	13. 7	14. 6	3. 2	7. 1
	16. 6	15. 7	--------	--------	4. 9	2. 4	--------	--------	8. 7	3. 5
	10. 8	13. 3	--------	--------	2. 4	. 9	--------	--------	1. 9	3. 0
	15. 2	15. 4	--------	--------	5. 0	4. 7	--------	--------	5. 5	5. 2
	12. 4	13. 4	--------	--------	3. 9	4. 3	--------	--------	4. 1	4. 8
	15. 2	15. 2	--------	--------	. 9	1. 2	--------	--------	1. 1	1. 1
	15. 2	13. 2	--------	--------	. 9	1. 0	--------	--------	1. 0	1. 1
	16. 0	15. 2	--------	--------	3. 9	3. 2	--------	--------	4. 5	3. 6
	12. 4	13. 3	--------	--------	3. 4	3. 7	--------	--------	4. 1	4. 3
	14. 8	14. 6	--------	--------	1. 2	1. 6	--------	--------	1. 3	1. 5
	14. 8	14. 6	--------	--------	1. 2	1. 9	--------	--------	1. 3	1. 3
Average..........	14. 19	14. 20	12. 20	11. 57	3. 19	3. 33	11. 95	17. 50	4. 01	4. 00

Series 2—Brookston and Miami Soils—Chemical Factors

DESCRIPTION, PROCEDURES

The two soils used in Series 2 are representative of upland soils in the Indiana-Ohio area developed from glacial material, and offer a contrast in soil structure. The Brookston was a silty clay containing 12, 44, and 44 percent sand, silt, and clay, respectively, having a very strongly developed blocky type of structure very stable to wetting. A clod of this soil crumbled easily between the fingers and broke into uniform sized cubes. Upon drying, it developed a checkerboard of cracks. The Miami was a clay loam containing 22, 46, and 31 percent sand, silt, and clay, respectively, having a weakly developed angular structure unstable to wetting.

Dosing treatments were designed primarily to investigate the effect of chemical clogging, particularly the effect of calcium and sodium. Replicate cores were prepared in the usual manner. Two cores of each soil type were dosed with normal effluent; 2, with effluent fortified with 100 and 200 p. p. m., respectively, of calcium applied as calcium sulfate; and 2, with effluent fortified with 100 and 200 p. p. m., respectively, of sodium applied as sodium sulfate.

TABLE 47.—Effect of various effluent dosing treatments on the soil core percolation rates of Brookston silty clay and Miami clay loam

	Soil core dosing treatments					
	Brookston silty clay			Miami clay loam		
	Sewage effluent			Sewage effluent		
	Control	+Ca	+Na	Control	+Ca	+Na
Percolation rate at start of dosing—cc./hr.:						
Dup 1	165.0	172.0	175.0	25.0	24.4	23.9
Dup 2	148.0	140.0	150.0	25.0	23.6	23.0
Average	156.5	156.0	162.5	25.0	24.0	23.45
Percent	100.0	100.0	100.0	100.0	100.0	100.0
Percolation rate after 70 days of dosing—cc./hr.:						
Dup 1	25.0	33.0	26.0	7.8	5.8	5.2
Dup 2	25.0	33.0	26.0	5.1	5.8	4.4
Average	25.0	33.0	26.0	6.45	5.80	4.80
Percent	16.0	21.2	16.0	25.8	24.2	20.5
Percolation rate after the accumulation of 1.0 gm. of suspended solids–cc./hr.:						
Dup 1	27.0	35.0	25.0	8.4	5.6	4.9
Dup 2	27.0	35.0	25.0	5.0	5.6	4.1
Average	27.0	35.0	25.0	6.70	5.60	4.50
Percent	17.3	22.4	15.4	26.8	23.4	19.2

RESULTS, DISCUSSION

The pertinent percolation rate data on all of the cores are given in table 47. Varying the concentration of sodium or calcium from 100 to 200 p. p. m. had no effect on percolation rates. The like treatments therefore have been considered as duplicates in the tabulation. Applied to the Brookston soil, calcium-fortified effluent maintained higher percolation rates than did the normal effluent controls. The rates of the sodium-fortified effluent cores were about the same or slightly less than the controls. Applied to the Miami soil cores, the sodium-fortified effluent resulted in the lowest rates.

The general behavior of the percolation rates over the complete dosing period are plotted in plates 20 and 21. Each curve is the average of duplicate cores.

Over the first 10 days, while the cores were being dosed with tapwater, the rates fall off rapidly and then tend to approach an equilibrium. This trend is more pronounced with the Brookston soil, which might have been expected. It is a heavy soil with well developed blocky structure, in which the aggregate or structural particles tend to shrink and swell depending on moisture. The reduction in the percolation rates reflects the swelling of the soil as it saturates.

In both sets of cores, effluent dosing, started on the fifteenth day, was immediately reflected in the downward trend of the curves. The specific effect of effluent dosing is more apparent from the trend curves than it is from the basic data of table 47. For instance, in plate 21, it is apparent that the trend towards greater clogging by the sodium-fortified effluent starts immediately. For the Brookston soil, plate 20, the calcium-fortified effluent dosing caused the least clogging.

The results with the Brookston and the Miami soil confirm the trends previously noted with the Genesee soils. The two soils, both of which had developed structure, show the detrimental effect of an increased sodium ratio.

PLATE 20

EFFECT OF CALCIUM AND SODIUM FORTIFIED EFFLUENTS ON CORE PERCOLATION RATES OF BROOKSTON SILTY CLAY

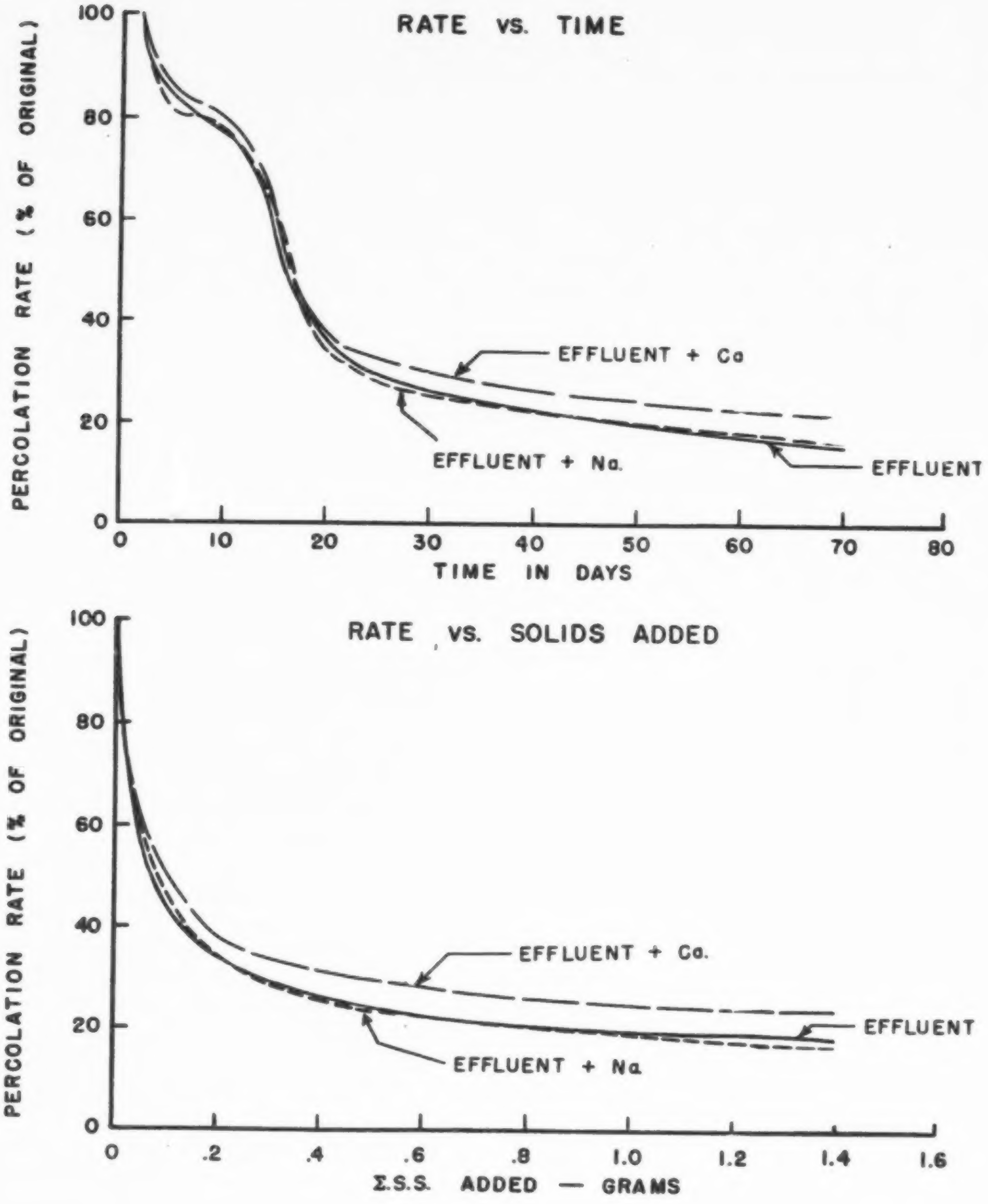
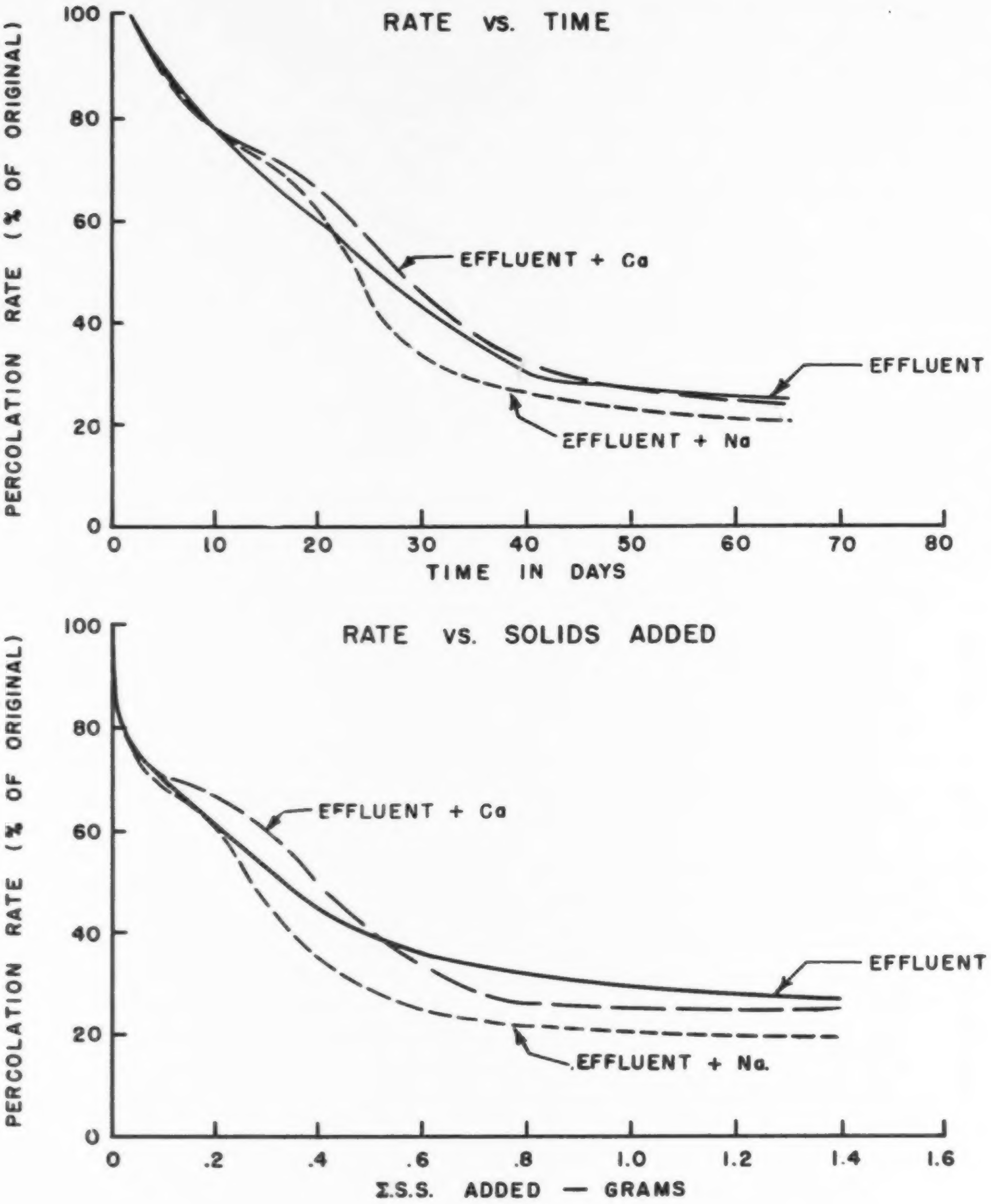


PLATE 21

EFFECT OF CALCIUM AND SODIUM FORTIFIED EFFLUENTS ON CORE PERCOLATION RATES OF MIAMI CLAY LOAM



Series 3—Fox Soils—Physical, Chemical, and Biological Factors

DESCRIPTION, PROCEDURES

In Series 3, a more complete and detailed separation of the clogging due to physical, chemical, and biological factors was attempted. As in the previous series, two soils of contrasting physical properties were included. These were a Fox sandy loam and a Fox clay loam. The Fox sandy loam, which contained 62, 19, and 19 percent sand, silt, and clay, respectively, had no developed structure. The Fox clay loam, which contained 27, 33, and 40 percent sand, silt, and clay, respectively, had a well-developed prismatic type of structure fairly unstable to wetting. In the natural state, Fox sandy loam is a well-drained soil and has a percolation rate in the range of 10 minutes per inch or faster. The clay loam is poorly drained and has a borderline percolation rate for acceptability for absorption field purposes. Ten replicate cores of each soil, prepared in the standard manner, were used in the study.

The dosing treatments were designed to reduce clogging caused by physical or biological factors. To reduce the biological clogging, a normal septic tank effluent was disinfected by the addition of 1,000 p. p. m. formaldehyde. To reduce the physical clogging, an aliquot of the same effluent was coagulated by the addition of 1,000 p. p. m. ferric chloride and filtered through a coarse filter paper. One aliquot of effluent was both filtered and disinfected, thus reducing both the physical and biological factors that might cause clogging. Normal effluent and tapwater dosed cores were run concurrently as controls.

RESULTS AND DISCUSSION

The trend of the percolation rates with time according to the various effluent treatments are shown in plates 22 and 23. Each curve is the average trend of duplicate cores. The rates are plotted as percent of original rates, in order to have a common base for comparison of the various treatments. The same trend and separation of effects is obtained, whether the original rate is considered as the start of water dosing, or after 20 days when treatment dosing was started.

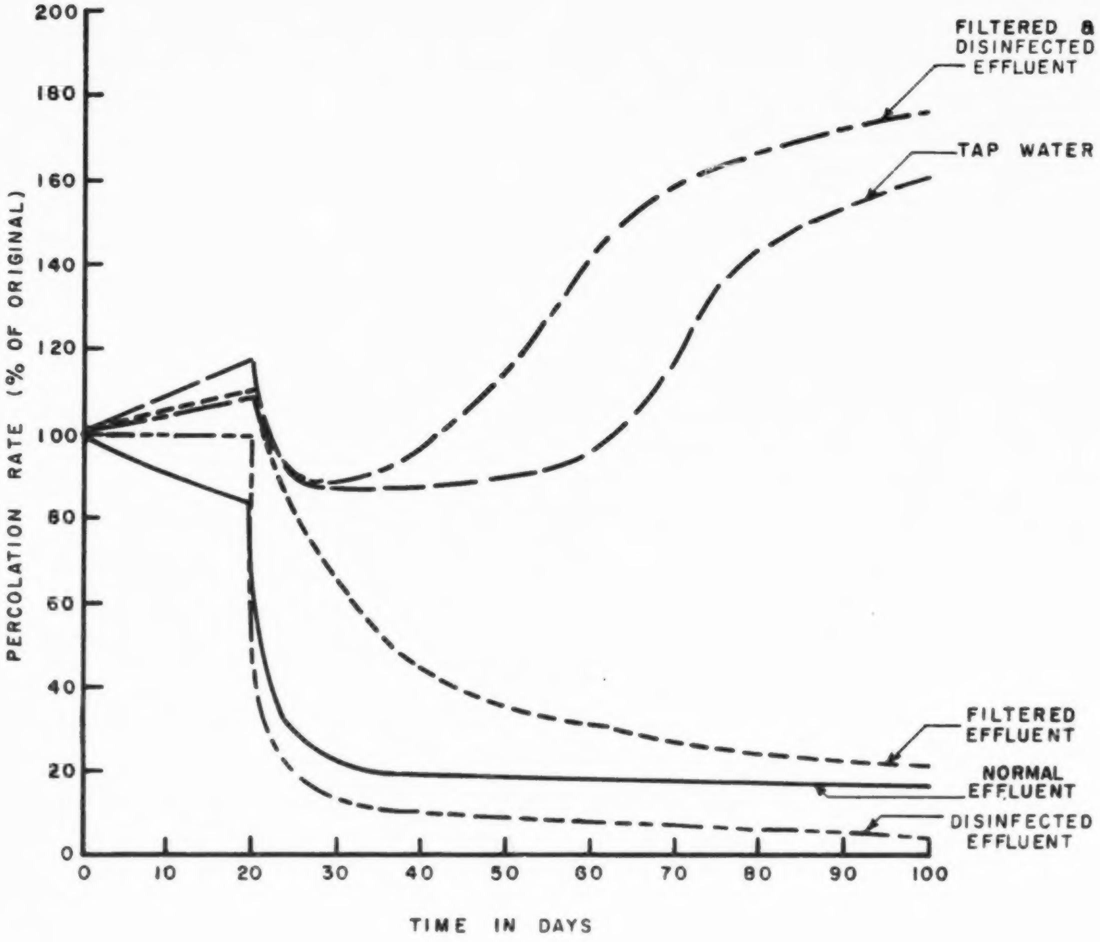
The greatest differences in clogging due to treatment were observed with the clay loam soils, plate 22. This would be expected because of the structural nature of this soil. The filtered-disinfected effluent, presumably removing or at least reducing the effect of physical and biological factors and leaving only chemical factors, affected soil core percolation rates little differently than did the tapwater. In both cases, the percolation rates increased during the period of the test, whereas the rates for cores dosed with normal effluent decreased. The disinfected effluent caused greater reduction in percolation rates than normal effluent, an effect which has been noted in previous studies. With the normal effluent, the rates decrease. At the end of the test, they were only about 17 percent of the originals. The filtered effluent, containing less suspended material, caused less clogging than the normal effluent. The rate of clogging by the filtered effluent was also slower, as evidenced by the gentler slope of the rate curve. It is somewhat surprising that the removal of solids did not reduce the clogging to a greater extent. One explanation is that the addition of the ferric chloride might be responsible. A comparison of the rates of cores dosed with tapwater, and with tapwater plus ferric chloride, plate 24, indicates that ferric chloride did have some adverse effect on tapwater percolation rates. Thus, benefit from the removal of suspended material may have been partially offset.

The clogging trends of the sandy loam cores were rather similar to the trends of the clay loam cores, except that the differences in clogging were of a smaller magnitude. The reduction in percolation rates during preliminary tapwater dosing was greater, as shown on plate 23. This greater reduction is probably due to the differences in the soils, the sandy loam being more easily slaked and dispersed by water. The reductions during dosing treatments were less than with the clay loam, but the different treatments showed similar trends.

With these soils, a reduction in suspended material, or in both suspended material and biologic activity, resulted in less clogging, while reduction in biologic activity alone caused more clogging, than normal effluent.

PLATE 22

TREND OF PERCOLATION RATES OF FOX CLAY LOAM CORES UNDER VARIOUS EFFLUENT DOSING TREATMENTS

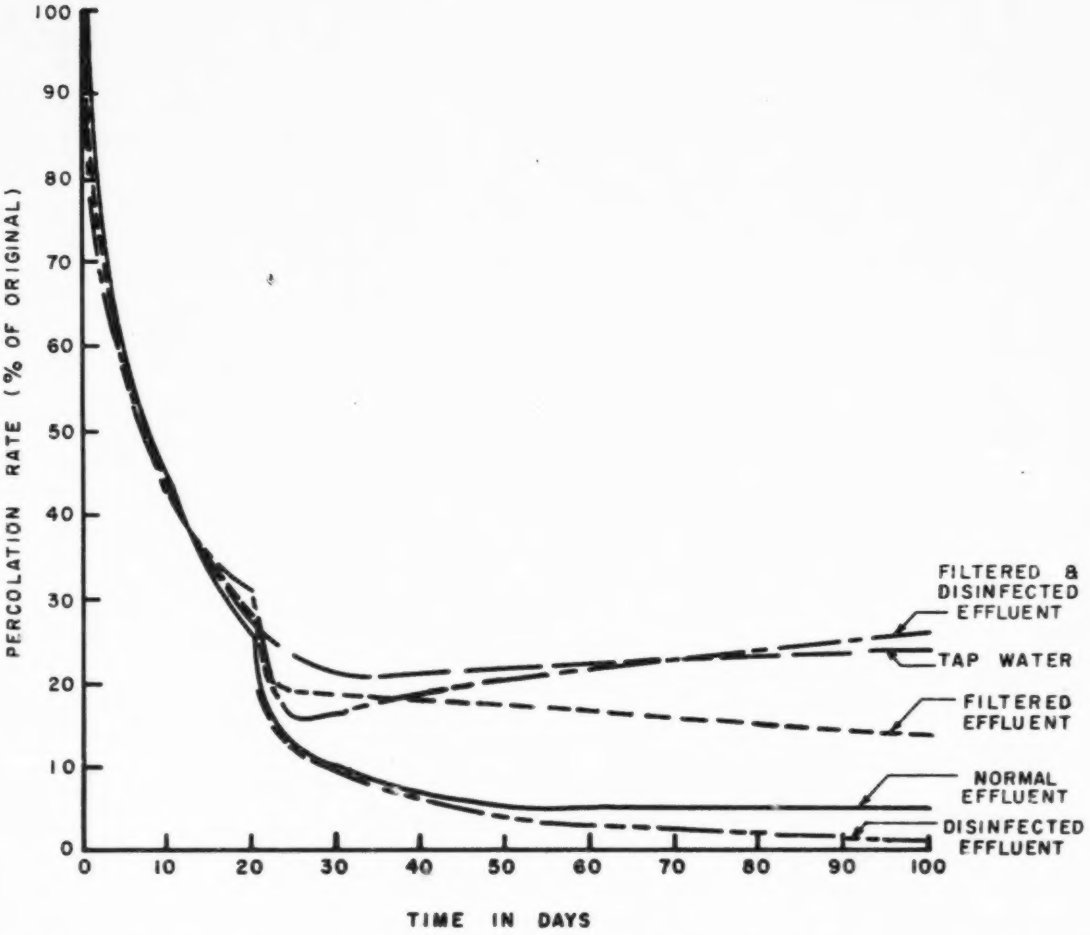


Series 4—Genesee Silt Loam—Fresh versus Septic Sewage

In a previous report (2), it was noted that soil clogging was directly related to the amount of solids in the effluent. There was also some indication that raw sewage solids caused more clogging than effluent solids. This trend seems reasonable when the nature of the solids is considered. Fresh sludge solids tend to be gummy and drain slowly, while digested solids tend to be granular

PLATE 23

TREND OF PERCOLATION RATES OF FOX SANDY LOAM CORES UNDER VARIOUS EFFLUENT DOSING TREATMENTS



and drain well. These characteristics might well affect soil clogging. The following study was designed to investigate this effect.

DESCRIPTION, PROCEDURES

A set of 12 soil cores was prepared in the standard manner, using a Genesee silt loam soil whose properties were described on page 65. After 10 days of preliminary dosing with tapwater to obtain the basic percolation rate of each core, the cores were divided into three groups of three each. The corresponding cores in each group had comparable rates at the start of treatment dosing, as may be noted in table 48.

PLATE 24

EFFECT OF $FeCl_3$ ADDITION ON CLOGGING BY TAP WATER

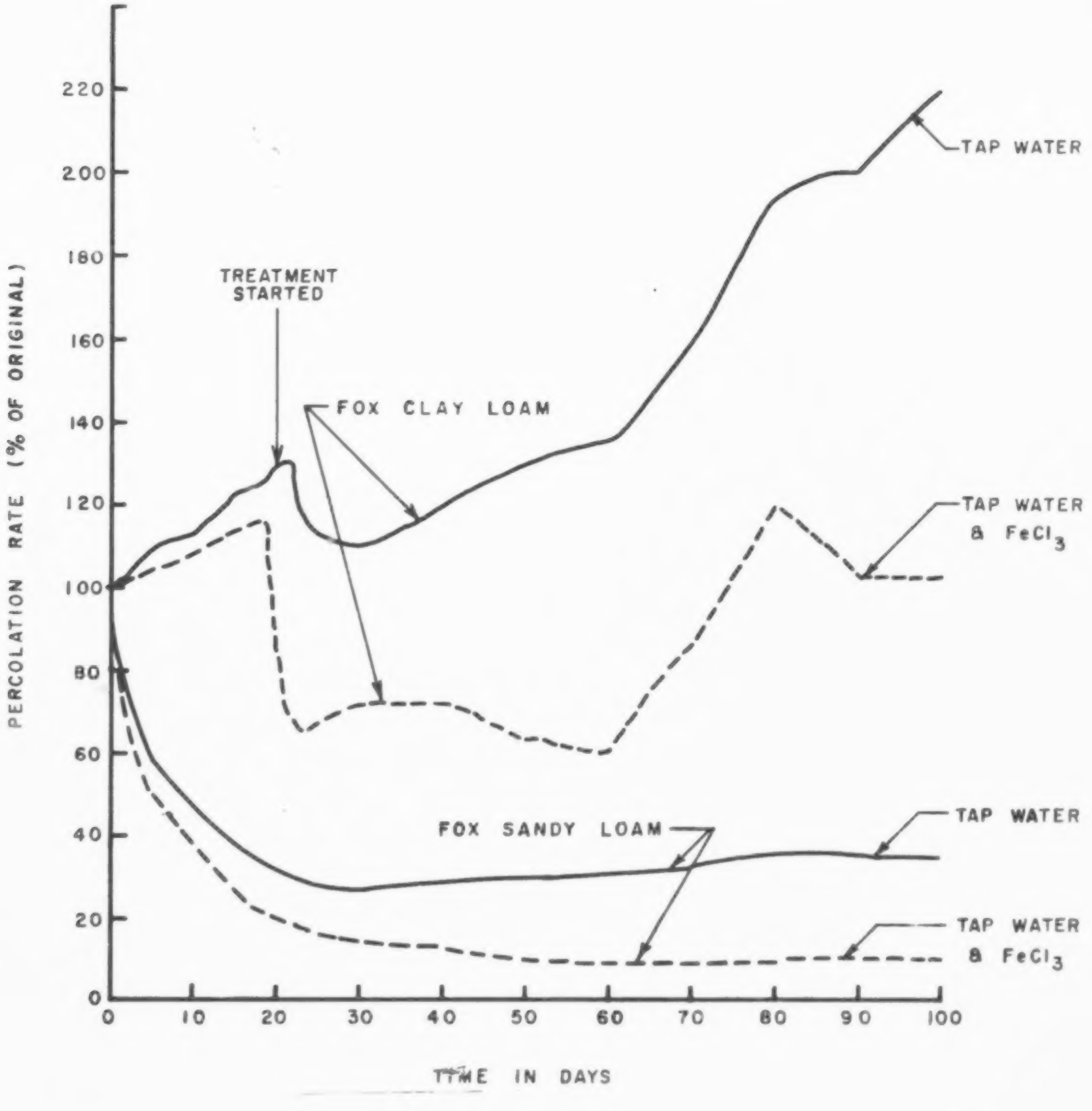


TABLE 48.—Percolation rates of cores dosed with sewage and effluents of various ages

	Filtered fresh sewage					Normal effluent					Well-aged effluent				
	1	2	3	Average		1	2	3	Average		1	2	3	Average	
	cc./hr.			cc./hr.	Percent	cc./hr.			cc./hr.	Percent	cc./hr.			cc./hr.	Percent
Rate at start of dosing (2d day)	31. 0	27. 0	25. 0	27. 7	100. 0	30. 0	29. 0	27. 0	28. 7	100. 0	30. 0	26. 0	25. 0	27. 0	100. 0
Rate at end of dosing (80 days)	3. 8	4. 1	4. 1	4. 0	14. 4	3. 7	3. 3	3. 2	3. 4	11. 8	2. 9	3. 0	3. 1	3. 0	11. 1
Rate after 1.4 gms. suspended solids were added	4. 1	4. 2	4. 0	4. 1	14. 8	5. 5	4. 1	3. 7	4. 4	15. 3	7. 5	6. 8	5. 9	6. 7	24. 8

The dosing treatments, which were selected to represent a wide range in the digested condition of the solids, were: filtered fresh sewage, normal septic tank effluent, and well-aged effluent. The sewage collected daily represents undigested solids. In order to approximate the amount of suspended solids in the effluents, the sewage was filtered through a glass wool pad before being dosed to the cores. The normal septic tank effluent, obtained daily from experimental tanks, represents an intermediate digested condition of the solids. The well-aged effluent, obtained from a septic tank that had been discontinued and allowed to stand for some 6 months, represents well digested solids.

The cores were dosed continuously for about three months. Percolation rates and the amounts of effluents and solids added were measured daily.

RESULTS, DISCUSSION

The average solid characteristics of the dosing solutions are given in table 49.

The trend of the percolation rates of the cores is shown in plate 25. Each curve represents the average of three cores. On a time basis, there is very little difference in clogging among the three treatments. At the end of the 80-day treatment, the sewage cores had slightly higher percolation rates. Differences in the daily solids concentrations and dosing volumes resulted in difference in weight of solids applied to each core during the test. The trends of rates with suspended solids added show that the well-aged effluent caused less clogging, and the filtered fresh sewage more, than the normal effluent.

Percolation rates of the individual cores are given in table 48. An analysis of variance of these data shows that there were no significant differences between the rates at the start of the dosing, but that there were significant differences (at the 1 percent level) in the rates at the point where 1.40 gm. of suspended solids had been added.

TABLE 49.—Average solid characteristics of dosing solutions

	Total solids (p. p. m.)	Suspended solids (p. p. m.)	$^{vss}/_{ss} \times 100$ (percent)
Filtered fresh sewage	824	104	(1)
Normal sewage effluent	834	114	58. 4
Well-aged effluent	657	205	50. 7

[1] Not determined.

Field Studies

INTRODUCTION

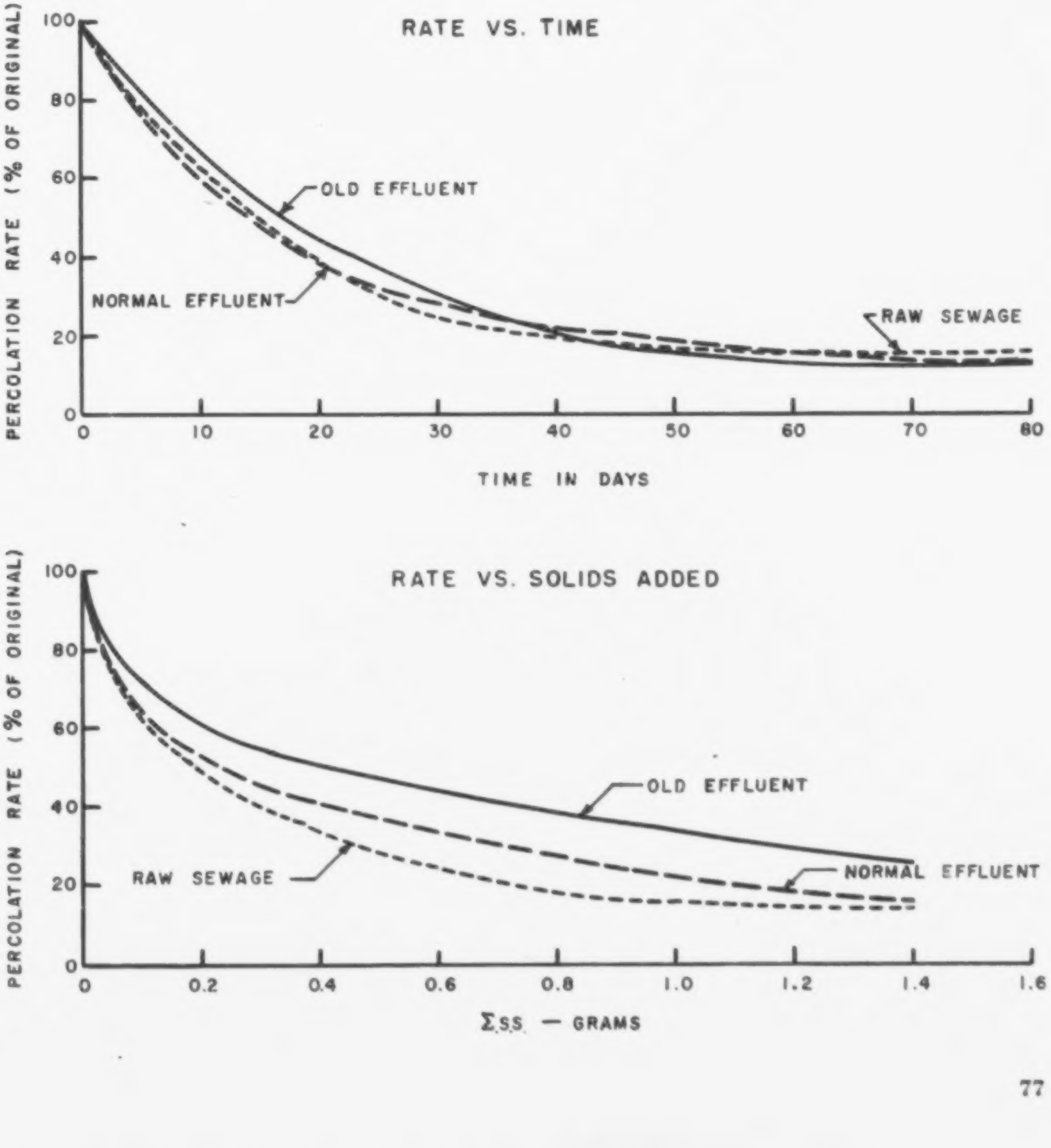
Laboratory studies on manually packed soil cores provide some of the basic concepts on clogging characteristics of septic tank effluent. However, many conditions operative in an absorption field are not reproducible or controllable in laboratory core studies. Such factors include the effect of underlying soil, temperature, alternate wetting and drying, roots, etc. Consequently, it was necessary to obtain conditions more comparable to those of an actual absorption field to investigate further the clues furnished by laboratory studies.

DESCRIPTION, PROCEDURE

A site in the laboratory yard having homogeneous soil was selected for the study. The site had a

PLATE 25

TREND OF PERCOLATION RATES OF SOIL CORES DOSED WITH SETTLED RAW SEWAGE, NORMAL SEPTIC TANK EFFLUENT AND OLD SEPTIC TANK EFFLUENT



uniform slope of about 10 percent, with a southern exposure. Three inches of black loamy surface soil graded into a reddish silty clay loam which continued to get heavier with depth, becoming at about 30 inches a tight, plastic clay.

Twelve 4-inch-diameter auger holes, 15 inches deep, were bored at 2-foot intervals across the slope. Appearance of the soil, its texture and structure, in the bottom 6 inches of each hole was very similar, and it was judged that all the holes should have similar absorption capacities. Later percolation measurements confirmed the observation. A 4-inch-diameter farm tile was then forced into each hole to within 4 inches of the bottom, leaving the last 4 inches unlined. The tile extended 1 inch above the soil surface. In 4 of the holes, an additional 2 inches of soil were removed from the bottom and replaced with a concrete plug, the intention being to reduce vertical movement of water out of the holes to permit a comparison of lateral and vertical seepage.

The bottom and sides of the cavities were scarified to remove smeared surfaces. All loose material was carefully removed. The holes were filled with washed pea gravel up to the bottom of the tiles.

Dosing Treatments.—All holes were dosed with tapwater for a week, in order to approximate saturated conditions and to determine the equilibrium percolation rates. The dosing treatments are outlined in table 50. The effluent used for dosings was a daily composite sample from a 500-gallon laboratory septic tank. Half of the sample was disinfected by adding 1,000 p. p. m. formaldehyde and allowed to stand overnight at 39° F. before using. Tapwater was disinfected in the same manner. The dosing solutions were removed from storage approximately 2 hours before being used and allowed to come to air temperature.

All holes were dosed with an equal volume of effluent daily. The volume was so adjusted as the experiment progressed that the slowest hole would absorb all of the effluent added each day, so that at the start of each day all holes would be empty.

Daily dosing for 3½ months was followed by a 4-month resting period, during which time the holes were plugged and protected from the weather. After the 4-month resting period, tapwater dosings were made for 30 days to note the effect of the resting period on absorption capacity.

Dosing Pattern and Percolation Rate Measurements.—Each time a volume of effluent was added, a liquid level measurement was made and subsequent measurements were made at half-hour intervals. Percolation rates were calculated in two ways: the average rate, i. e., total fall in liquid level over the day in inches divided by the time in hours; and the equilibrium rate, i. e., fall in liquid level over the last 30-minute period of the day divided by 0.5. The equilibrium rate was always measured under minimum head conditions.

TABLE 50.—Dosing treatment schedule of field soil clogging study

Hole No.	Dosing period			
	Sept. 1 to Sept. 8 (7 days)[1]	Sept. 8 to Dec. 21 (105 days)	Dec. 21 to Apr. 20 (120 days)[2]	Apr. 15 to May 15 (30 days)[1]
1		Tapwater		
2		do		
3		Disinfected tapwater.		
4		do		
5		Effluent		
6		do		
7		Disinfected effluent.		
8		do		
9		Tapwater		
10		do		
11		Effluent		
12		do		

[1] All cores dosed with tapwater during this period.
[2] No dosing during this period. (Soil resting.)

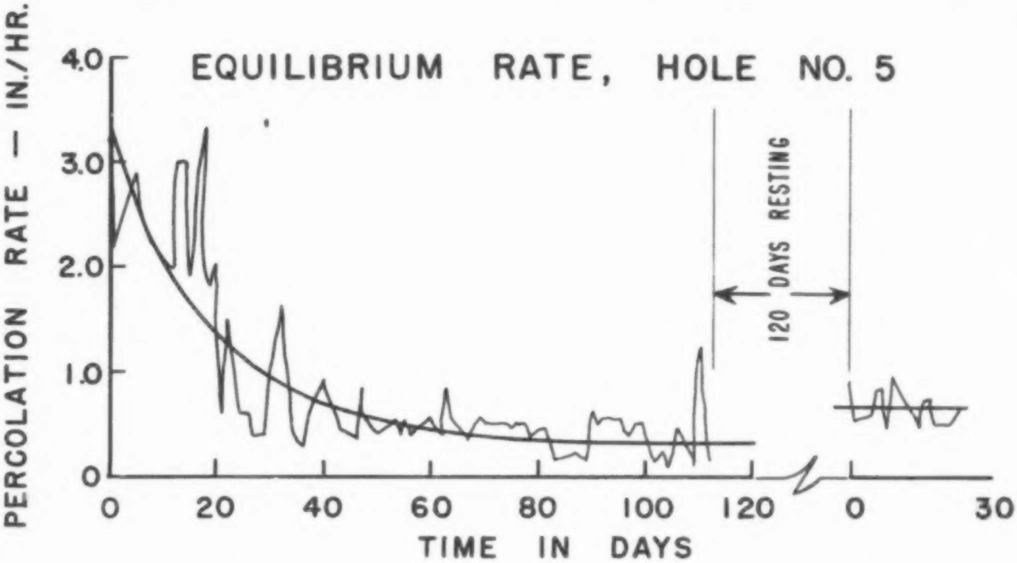
RESULTS AND DISCUSSION

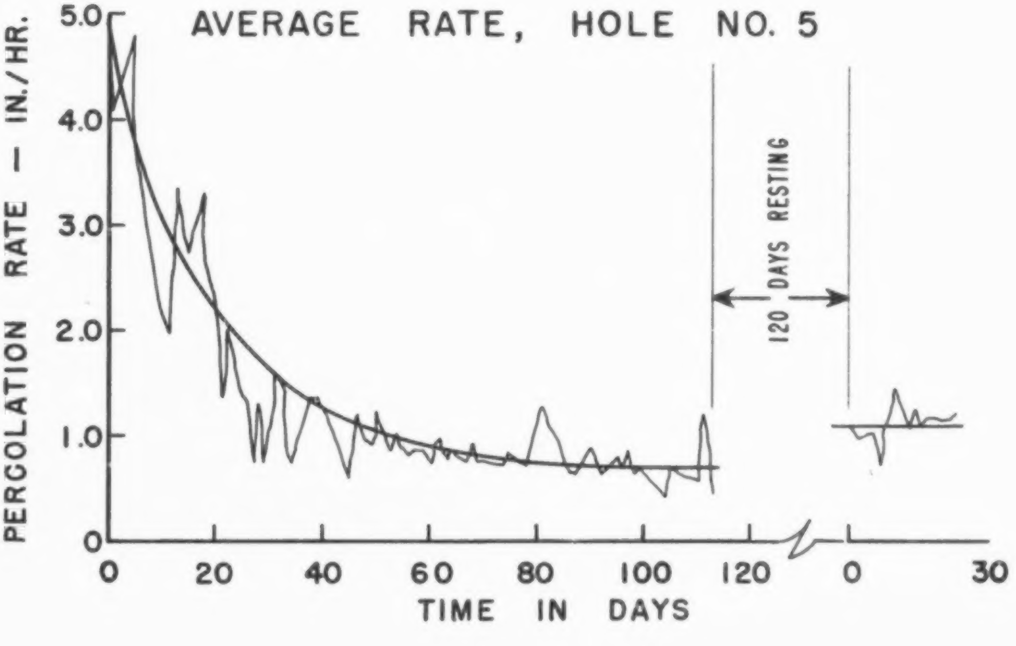
There was a tendency for the difference between any daily average percolation rate and the comparable daily equilibrium rate to be greater during the first several days of dosing. This was probably due to a lack of saturation of the soil during this time. It was also observed that even toward the end of the study the percolation rates during the first part of the day were faster than toward the end of the day. Evidently, during the overnight period when the holes were not filled with effluent, enough internal drainage took place in this soil to affect the percolation rates materially, causing a faster rate when effluent was again added on the next day.

Both the average and equilibrium percolation data were variable from day to day. The raw data on one of the test holes, typical of all of the data, are shown in plate 26. Despite daily variability, curves fitted to the data by eye are sufficiently accurate to indicate the trends and the

PLATE 26

TREND OF PERCOLATION RATES IN FIELD TEST HOLES WITH TIME





magnitude of the soil clogging caused by individual treatment. Curves were fitted to both daily average and daily equilibrium rate data for all of the holes. Rates at critical points in the dosing period, taken from these curves for a comparison of treatments, are given in tables 51 and 52. Either comparison shows the same relative trends in clogging caused by the various effluents.

The percolation rates of all of the holes were about the same at the start of the study, verifying the earlier observation that the soil was homogeneous. The average rates were about 5.0, and the equilibrium rates about 3.5 inches, per hour. Soils having percolation rates of this magnitude would be acceptable for absorption fields according to the usual specifications.

TABLE 51.—Average percolation rates (in inches per hour) in field test holes under various dosing treatments

	Natural holes								Holes with bottom plug			
	Tapwater		Disinfected tapwater		Effluent		Disinfected effluent		Tapwater		Effluent	
Hole No.	1	2	3	4	5	6	7	8	9	10	11	12
Percolation rate at start of study	5. 00	5. 00	5. 00	5. 00	5. 00	5. 00	4. 50	4. 50	4. 10	4. 10	4. 10	4. 10
Percolation rate after dosing for 112 days	. 75	. 90	. 70	. 70	. 70	. 70	. 20	. 25	1. 20	1. 30	. 65	. 75
Percolation rate after resting 120 days and dosing with tapwater for 30 days	1. 30	1. 35	1. 10	1. 25	1. 10	1. 15	1. 05	1. 30	1. 50	1. 45	1. 30	1. 35

TABLE 52.—Equilibrium percolation rates (in inches per hour) in field test holes under various dosing treatments

	Natural holes								Holes with bottom plug			
	Tapwater		Disinfected tapwater		Effluent		Disinfected effluent		Tapwater		Effluent	
Hole No.	1	2	3	4	5	6	7	8	9	10	11	12
Percolation rate at start of study	3. 50	3. 00	3. 50	3. 50	3. 50	3. 50	3. 50	3. 00	3. 50	3. 50	3. 50	3. 50
Percolation rate after dosing for 112 days	. 55	. 50	. 50	. 55	. 30	. 45	. 15	. 15	. 50	. 50	. 35	. 35
Percolation rate after resting 120 days and dosing with tapwater for 30 days	. 55	. 65	. 75	. 65	. 65	. 75	. 65	. 65	. 80	. 80	. 75	. 75

The rates in the holes having concrete plugs were little or no different than the rates in holes without plugs. Evidently, a major part of the seepage was laterally through the sides. The slope of the site and the tendency for the soil to be heavier and less permeable with depth would favor this type of movement.

The conditions under which the equilibrium rates were measured were more comparable to probable moisture conditions in operating tile fields. The rates were measured under minimum head conditions. For these reasons all following comparisons have been made on the basis of the equilibrium rates.

After dosing the test holes for 112 days, the effect of the various effluent treatments had established a definite pattern, similar to that found in the laboratory soil core studies. It can be noted in table 52 that the effluent dosings in all cases caused more clogging than the tapwater dosings. The rates for the normal effluent-dosed holes at the end of 112 days were 0.30 and 0.45 inch per hour, averaging about 0.38 inch per hour. The rates in the tapwater holes were 0.50 and 0.55 inch per hour, averaging about 0.52 inch per hour. On a percentage basis, the tapwater hole rates decreased to about 16 percent of the original rate, while the normal effluent hole rates decreased to about 11 percent.

The disinfected tapwater showed no different clogging than the normal tapwater. The disinfected effluent did cause more clogging than the normal effluent. At the end of the 112 days of dosing, the equilibrium rates of the normal effluent holes averaged 0.37 inch per hour, and the disinfected effluent holes, 0.15 inch per hour, or 11 percent and 5 percent of the original rates, respectively. This trend is the same as noted in the core studies, and again indicates that bacterial activity in the tile field is beneficial from the overall soil clogging viewpoint.

When re-dosing started after the four-month resting period, the rates for all of the holes but one showed a decided increase over the rates prevailing before the resting period. The percolation rates of the effluent holes increased from 0.29 to 0.70 inch per hour on the average, while those of the tapwater holes increased only from 0.52 to 0.70 inch per hour. The increased rates stayed at the higher level for the 30 days of such dosing. The holes that were previously dosed with effluent had a greater relative increase in rate than did the holes originally dosed with tapwater. The greater increase shown by the effluent holes may be related to an improvement of the soil structure under the effluent dosing. In surface soil, improvement of soil structure and of soil moisture absorption capacity may be obtained by the addition of organic matter such as animal manures or plant residues. Having somewhat comparable conditions with the dosing of effluents, similar improvement could be expected if wetting and drying cycles were provided.

At the completion of the studies and after the holes had dried for about six months, soil samples were taken for aggregate analysis. These were air dried and particles that passed an eight- but were retained on a 14-mesh sieve were collected. Aggregate analyses were run on these samples to note any effect of dosing treatment on aggregate stability, an index of soil structure. The analyses were made by the Bryant short method (20).

The results of the aggregate analyses are given in table 53. The soil examinations were made following subsequent use of the holes for soap and detergent studies, section H, page 115. It may be noted that the soils dosed with normal effluent tend to have a higher aggregate stability than the soils dosed with tapwater, 59 as compared to 50 percent in the unplugged holes, and 71 to 68 percent for the plugged holes. If all of the soils dosed with effluent are compared with all of the soils dosed with tapwater regardless of the subsequent treatment, the stabilities are 60 and 53 percent, respectively.

TABLE 53.—Effect of various effluent dosing treatments on aggregate stability [1]

	Natural holes								Holes with bottom plug			
	Tapwater		Disinfected tapwater		Effluent		Disinfected effluent		Tapwater		Effluent	
	Soap	Detergent	Soap	Detergent	Soap	Detergent	Soap	Detergent	Soap	Detergent	Soap	Detergent
Duplicate 1	63	43	38	43	58	(2)	60	34	64	72	72	67
Duplicate 2	58	38	38	47	60	(2)	63	37	67	68	75	70
Average	60. 5	40. 5	38	45	59	....	61. 5	35. 5	65. 5	70	73. 5	68. 5
Average of main treatments	50. 5		41. 5		59. 0		48. 5		67. 8		71. 0	

[1] Each value in the table is the percentage of a 25-gram sample of soil aggregates between No. 8 and No. 14 mesh size retained on a No. 35 mesh sieve after sieving for 5 minutes submerged in water.

[2] These samples were lost.

SECTION F

Further Investigation of Effect of Zeolite Softener Salts

INTRODUCTION

Rudolfs (41) conducted bottle experiments using sewage-ripe sludge mixtures in the presence of various amounts of sodium chloride. A salt concentration of 0.2 percent had no effect on digestion; 0.5 percent concentration had only slight effect; but retardation of digestion was pronounced at 1.0 and 2.0 percent. Experimenting with a mixture of 0.525 sodium chloride plus 0.115 percent sulfates of magnesium and calcium, he found some stimulation of digestion.

Discussing the effect of various salts on bacterial cultures, Topley and Wilson (42) state that there is a concentration for nearly all salts which stimulates bacterial action, generally a very low concentration, beyond which toxic action develops, becoming more toxic as the concentration increases; that the toxic effects of univalent salts can be neutralized by bivalent salts, and in most instances vice versa; that electrolytes with bivalent cations are generally more toxic than those with univalent cations; and that salts of heavy metals are more toxic than lighter metals. It was further indicated that the toxic action of salt is less in the presence of proteins than in distilled water; that different organisms vary in their susceptibility to disinfectant action of the same salt; that addition of a salt to a germicide may increase or decrease the action of the germicide.

Rockwell and Ebertz (43) advance evidence that salt interferes with bacteriological activity in at least four ways, namely, dehydration, direct effect of chlorine ion, sensitization to carbon dioxide, and interference with proteolytic enzymes.

In a previous report (1), bottle experiments were described in which various concentrations of a sodium, calcium, and magnesium chloride mixture were added to sewage seeded with ripe sludge. An initial mixed salt concentration of 1.2 percent inhibited digestion, but this effect was reduced by mixing and flushing with fresh sewage. In two full-size tanks, a 2.4 percent concentration of mixed salts did dilute in the upper, but not in the lower, portion of the tanks during 19 days of raw sewage additions, amounting to 250 gallons per day. From these tests, it appeared that under influence of repetitive salt waste discharges to a septic tank, a toxic concentration might be reached. Tests with simulated repetitive water softener regeneration discharges along with raw sewage additions to a full-scale tank were suggested.

Septic Tank Studies

INTRODUCTION

An experiment was conducted to determine if chloride salts in the concentration, amount, and pattern of discharge to be expected from a home-type water softener would:

(1) Accumulate in toxic concentrations at the bottom of the tank.

(2) Affect performance of the tank as measured by removal of suspended solids and other parameters.

PROCEDURE

Concentrations Used.—From data giving the rate of flow, chloride content, and hardness at short intervals of time during regeneration of a home-type softener unit, probable concentrations of calcium, magnesium, and sodium chloride were computed, and concentration versus flow curves plotted on plate 27. The concentration-discharge pattern of water softener wastes to a septic tank was closely approximated by adding mixed salts

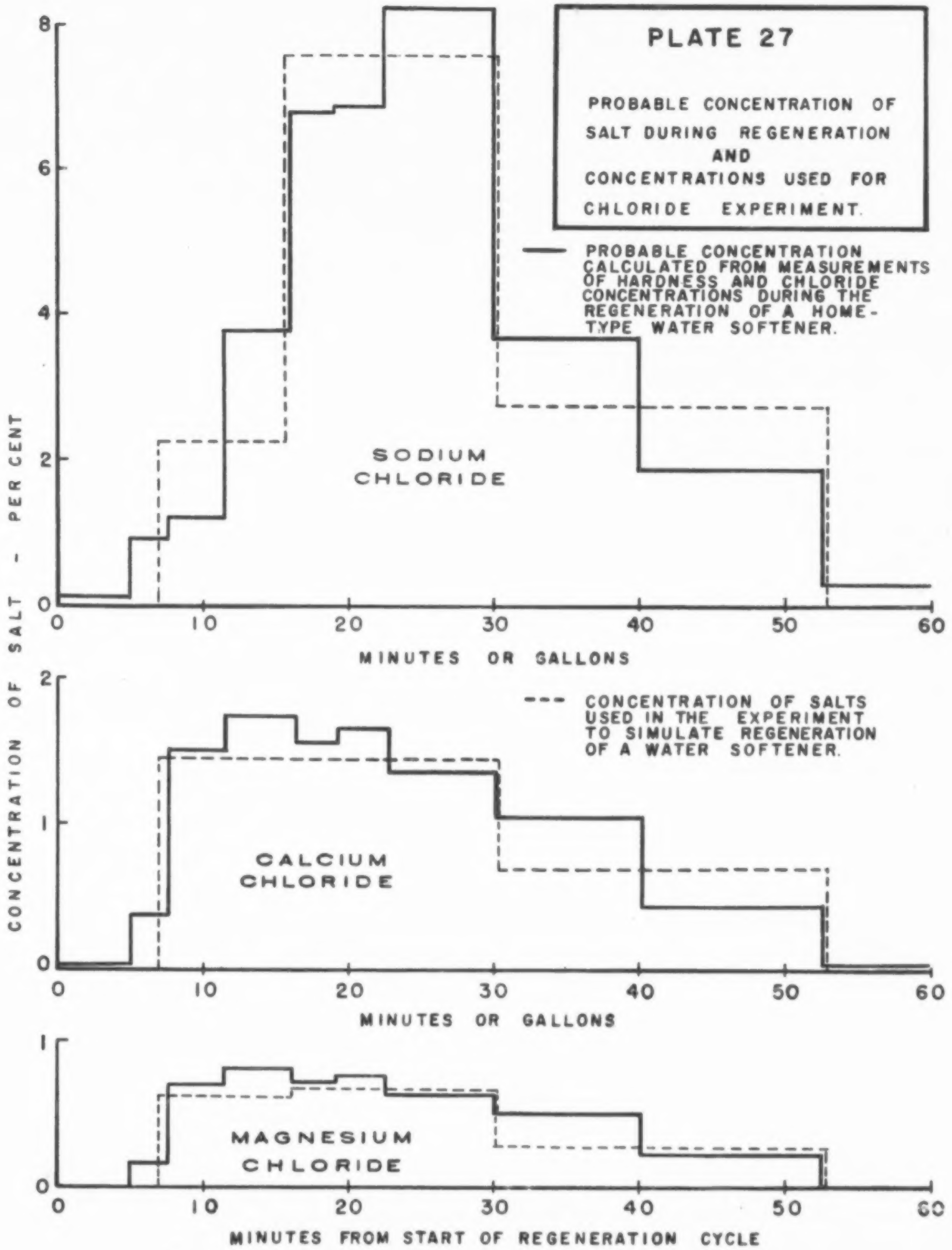


PLATE 27

PROBABLE CONCENTRATION OF SALT DURING REGENERATION AND CONCENTRATIONS USED FOR CHLORIDE EXPERIMENT.

Note: Flow equals ONE g.p.m.
Therefore, MINUTES equal GALLONS.

to the tank in three successive increments as indicated by the broken lines. The discharge rate was one gpm. The amount of salt and quantity of water for each increment is shown in table 54.

TABLE 54.—Quantity of mixed salts used to simulate waste from regeneration of a home-type water softener

Increment	Volume (gallons)	Pounds of salt		
		NaCl	$CaCl_2$	$MgCl_2$
1	10	1.9	1.2	0.5
2	14	8.8	1.8	.8
3	23	5.3	1.3	.6
Total	47	16.0	4.3	1.9

Experimental Plant.—A 455-gallon laboratory septic tank, tank 6S, was utilized for the experiment. A sketch of tank 6S is shown in appendix A, plate 52, and the layout on plate 1.

Three 55-gallon drums were installed above the tank with a valve arrangement so that each of the salt increments could be applied in the proper sequence.

Feeding and Sampling.—Salt to be used for each increment was dissolved in large carboys of warm water on Friday afternoon. On Monday morning, the carboys were emptied into the proper drum and tap water was added to give the proper volumes shown in table 54. Each drum was stirred thoroughly before discharging it to the tank.

The tank received 250 gallons of raw sewage in eight daily feeds, as described in a previous report (1). The 47-gallon salt feed was in addition to the regular feeds of raw sewage. The salt water was added each Monday morning immediately following the first feed, so that the tank would be in a disturbed state to approximate conditions prevailing where backwashing before regeneration is practiced. Salt feed was made at the rate of one gallon per minute.

In addition to sampling program described in the part I report, pages 68 to 72, chloride determinations were made on both the raw sewage entering and effluent leaving the tank. Once each week, chloride and specific gravity determinations were made on six samples taken from points traversing the depth of the tank.

RESULTS

Pounds of chloride retained in the tank, the highest concentration found, and typical distribution of chloride ion, as determined by the weekly cross section, are shown on plate 28.

The salt content of the tank built up rapidly during the first 6 weeks of salt application. After the initial build-up, an equilibrium was established in which salt content remained approximately constant. Starting about the 20th week, both chloride concentration and content began a rapid decline, and in a period of 8 weeks the tank effectively purged itself of salt. As shown by the frequency of dark effluents and rising effluent temperatures, plate 29, the purging action of the tank was closely related to increased rate of digestion accompanying warmer temperatures of spring.

At no time during the experiment did the action of the tank seem to be impaired by the weekly salt additions. The suspended solids removal efficiency of the tank ranged generally between 60 and 70 percent, with a sharp break attributable to the "spring upset" occurring during the 22d week. There was an increase in the sludge volume in the tank during the course of this experiment. However, the increase was no greater than the normal winter accumulation observed in other tanks during this same period. Digestion proceeded in a normal manner, as evidenced by the percentage of volatile solids in the effluent suspended solids, plate 29, and also by the presence of gas bubbles at the surface of the tank. In fact, on the basis of frequent but random observations, it seemed that more gas bubbles were breaking the surface in the salt tank than in the other tanks.

VIABILITY OF SLUDGE

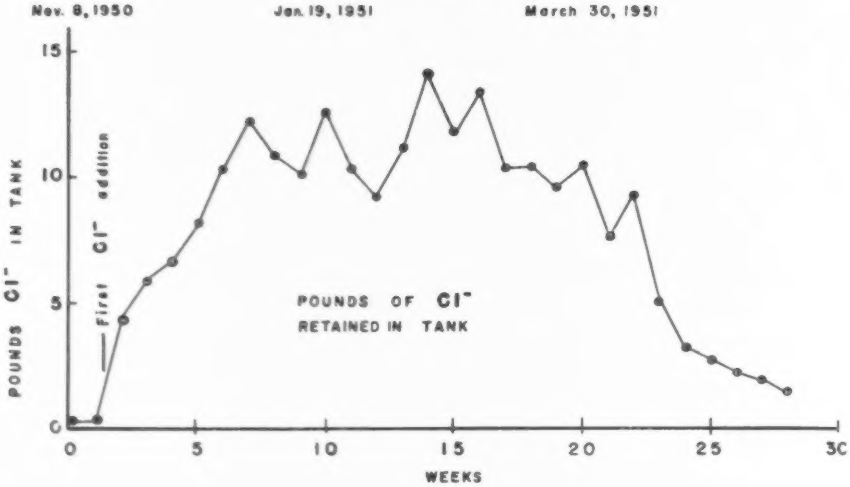
Reference to plate 28 shows that maximum chloride concentration reached 8,000 p. p. m., equivalent to 1.32 percent sodium chloride. Maximum salt concentration developed near the bottom of the tank.

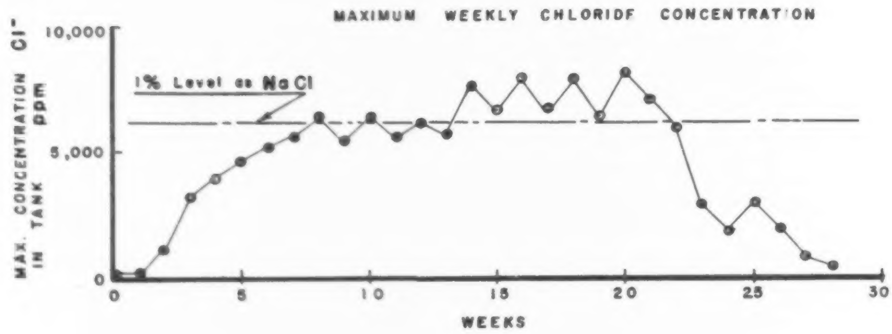
Previous bottle experiments (1) indicated that gas production by a sewage ripe sludge mixture was suppressed in the presence of a 1.2 percent mixed salt solution. As there was no evidence of reduced gas production in the salt tank, even though bottom concentrations exceeded the 1.2 percent limit, further investigations were made.

Ten cc. of sludge from the salt tank were used to seed each of a series of Nessler tubes containing

PLATE 28

TANK NO. 6S
CHLORIDE CONCENTRATIONS





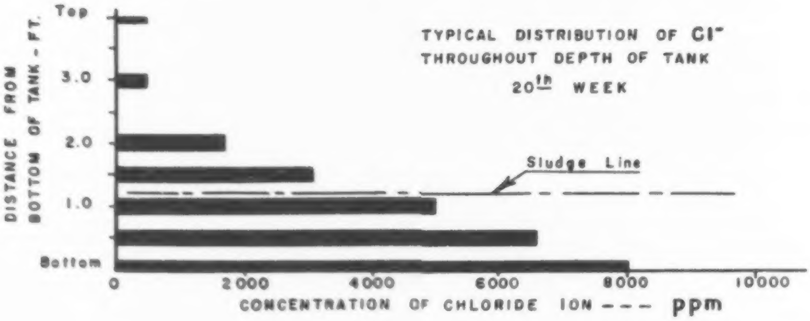
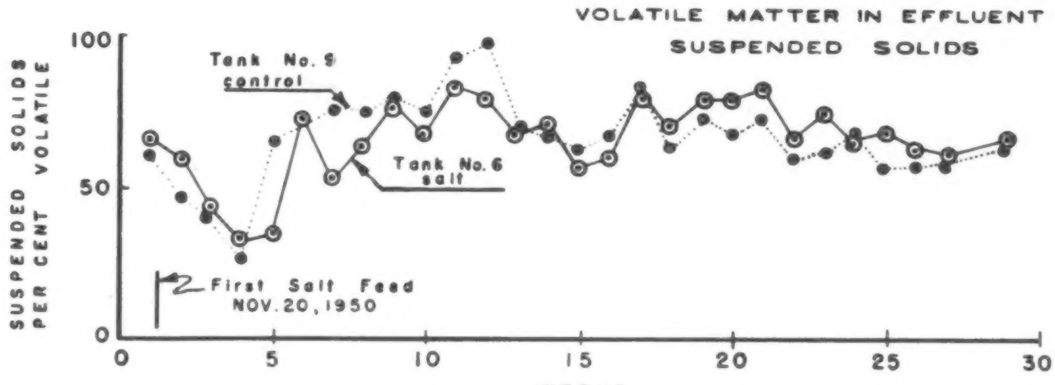
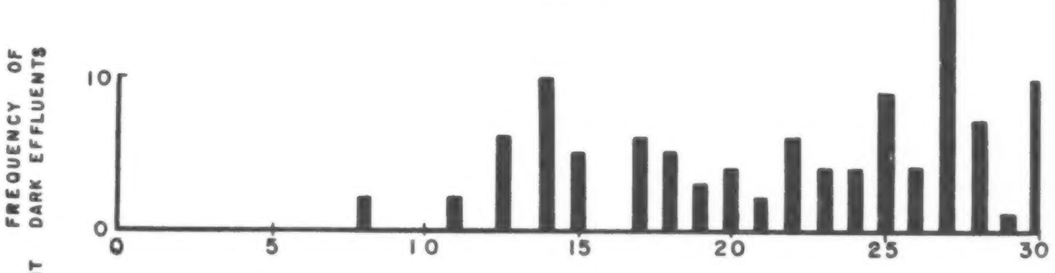
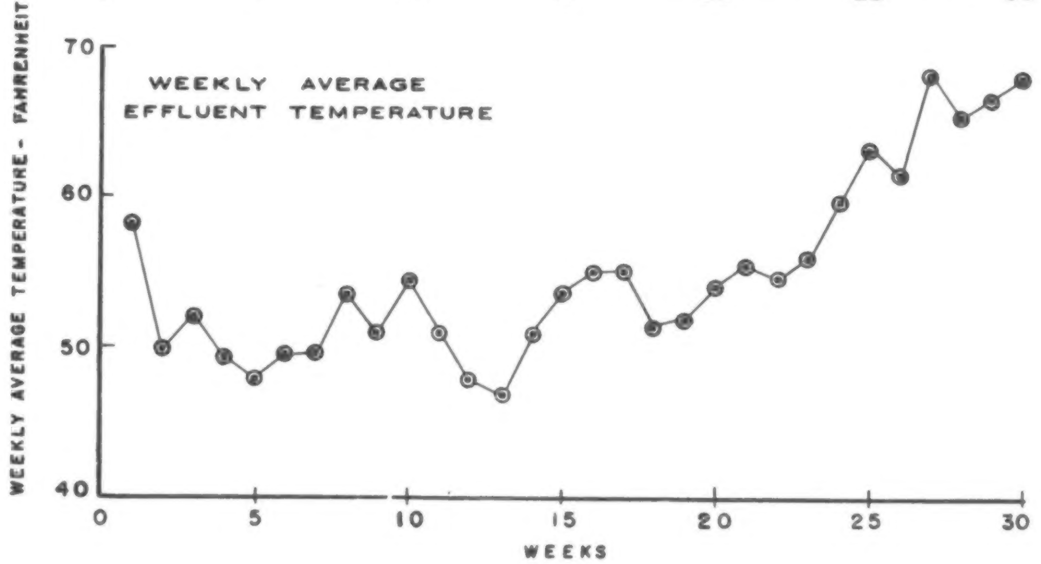


PLATE 29
TANK No. 6S
CHLORIDE EXPERIMENT







90 cc. of fresh, raw sewage. The proper weight of mixed salts was added to each tube to give minimum salt concentrations of 0, 1.0, 1.5, 2.0, and 2.5 percent. Salt contained in the sludge was not considered. Within each of the Nessler tubes, a 25 cc. test tube was inverted with the air exhausted in a manner analogous to the presumptive test for coliform organisms. In a like manner, another set of tubes was prepared using the same fresh sewage and duplicating the salt concentrations, seeded however with a normal septic tank sludge. Both sets of tubes were incubated at room temperature and periodic observations were made to determine the volume of gas trapped in the inverted test tubes.

Referring to plate 30, it is seen that at a salt concentration of 1 percent, gas production was strongly inhibited in the normal sludge, while the same concentration exerted little if any influence on the sludge from the salt tank. At concentrations of 1½ percent or greater, both sludges were inhibited, but the inhibition was less in the salt than in the normal sludge. It appears that, under influence of weekly salt additions over a long period of time accompanied by gradual increase of salt in the tank, sludge microbiota had become acclimated to a saline environment.

DISCUSSION

The concentration-time pattern for salt discharge was calculated from data obtained during regeneration of a home-type water softener. A total of 4.3 pounds $CaCl_2$ and 1.9 pounds $MgCl_2$ were applied to the tank during the simulated regeneration cycle. These salts would represent a weekly removal of approximately 41,000 grains total hardness expressed as $CaCO_3$. This hardness, coupled with a weekly regeneration cycle, represents a relatively severe condition for the septic tank system.

No adverse effect on the performance of the tank was noted during the 28 weeks of salt additions. Although salt stratification developed in the tank, and although some of the bottom layers reached concentrations which would be inhibiting to a normal sludge, no interference with digestion was evident. Perhaps there were two principal factors responsible for the favorable results. First, the purging action of the tank with the advent of warm weather prevented the high concentration layers from accumulating in quantity sufficient to envelop the sludge; and second, the sludge itself tended to become acclimated to a saline environment.

The septic tank used for this study was in normal operation and had accumulated approximately 10.2 cubic feet of sludge prior to the first salt addition. The salt concentration in the bottom of the tank built up over a period of several weeks, giving opportunity for gradual adjustment of microbiota to a saline environment. In essence, the test conditions were comparable to a tank adequately seeded with normal digesting sludge before it received brine discharges. Therefore, results obtained may not be applicable to a septic tank having little or no sludge accumulation such as a new installation, or a tank being returned to service after cleaning without seed sludge.

Bottle Study—Adjustment of Sludge to Saline Environment

INTRODUCTION

Bottle experiments summarized in a previous report (1) showed that a 1.2 percent mixture of sodium, calcium, and magnesium chlorides had a pronounced inhibiting effect on digestion of a sludge-sewage mixture. After 7½ days, only 7.4 percent as much gas was collected from the bottle containing the 1.2 percent salt mixture as from the control.

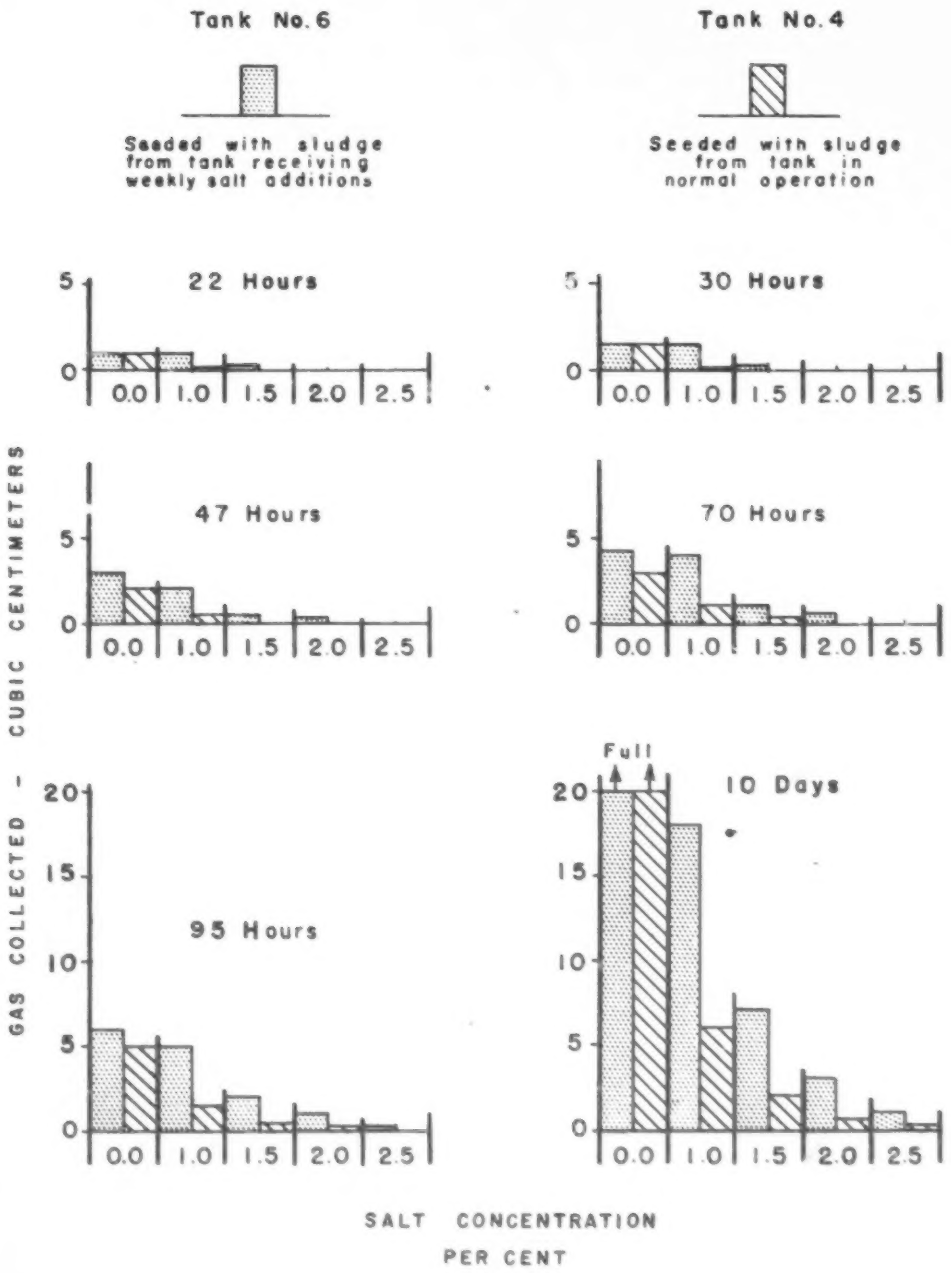
Results of the tank experiment and the test for sludge viability indicated that microbiota could become acclimated to a saline environment. Viability of sludge from a tank subjected to 28 weekly salt injections was not affected, but that of a normal sludge was inhibited, by a 1.0 percent salt solution. At higher salt concentrations, the salt sludge was less inhibited than the normal sludge. After 10 days, sewage seeded with normal sludge produced some gas in the presence of 2.5 percent mixed salts, indicating inhibition but not a true toxic effect.

The following bottle experiment was conducted to determine if microbiota would eventually overcome the effect of an initial high salt concentration. If recovery were accomplished after a long lag period, it would be further desirable to know if the lag period would again develop after another salt addition.

PLATE 30

CHLORIDE EXPERIMENT

Gas Production vs. Salt Concentration



PROCEDURE

Four 10-liter digestion bottles were prepared, using 9 liters of an 8-to-1 sewage to ripe sludge mixture, following the procedure described in section H, page 102. To two of the bottles, a mixture of calcium, magnesium, and sodium chlorides in the same proportion used for the tank study was added, to give a 1.2 percent concentration. All 4 bottles were then vigorously shaken and attached to gas collection devices.

Thirty-two days later, the apparatus were disconnected and supernatant liquors were siphoned off. The two control bottles were recharged with fresh raw sewage. From the same batch, sewage was taken to recharge the salt bottles. It was the intention to replace enough salt mix to the test bottles to keep the concentration at 1.2 percent. However, after the reassembly had been made, it was discovered that residual salt in the sludge had been neglected and enough mix had been added to bring the entire contents to 1.2 percent. Therefore, actual salt concentration after recharge was approximately 1.3 percent.

After recharging, the bottles were again vigorously shaken and reconnected to the gas collection apparatus. Gas was collected for another 28 days.

Volume of gas collected, temperature, and atmospheric pressure were recorded at convenient intervals. Precautions were taken in preparing the original sewage-sludge mixture and raw sewage for the recharge, to insure that each bottle received an equal amount of digestible material. For that reason, the course of digestion was followed by observing total gas production rather than the production per gram of volatile matter, as under these circumstances the two methods are equivalent.

RESULTS

Cumulative average volumes of gas collected from the duplicate control and test bottles have been plotted as functions of time on plate 31. An initial lag of 2½ days developed in the control bottles as compared with 9½ days in the test bottles. After overcoming the lag, digestion proceeded in the test bottles at approximately the same rate as the controls. The difference in the volumes of gas collected after 32 days is not considered significant.

After recharging, there was no appreciable lag period in either set of bottles. The curves indicate that progress of digestion was substantially the same in both test and control bottles.

DISCUSSION

As in previous experiments, a long lag was observed in presence of a 1.2 percent salt mixture. Suppression of gas production was complete for approximately 5 of the 9½-day lag. However, recovery from the effects of the salt was complete, as evidenced by the relative amount of gas produced in 32 days.

Recharging with a salt sewage had no appreciable effect on the test bottles, even though the second salt concentration was slightly higher than the first. After recharging, erratic gas collection curves developed for both sets of bottles. However, the same general pattern of behavior is evident. The small difference in total gas collected in 60 days can be attributed to experimental error, and is not considered significant.

Soil Clogging Studies

INTRODUCTION

It was noted in section E of this report that a high sodium ratio in irrigation waters has an adverse effect on soil absorption properties. It was found that the addition of sodium sulfate to a septic tank effluent caused increased clogging of soil cores. It may be calculated from data in table 54, page 84, that approximately 75 percent of the cations in spent softener regeneration brines may be sodium. Discharge of this material to a septic tank results in an increased concentration of salts and an increased proportion of sodium in the effluent. In view of these two factors, a soils study was conducted concurrently with the tank experiment on softener salts.

PROCEDURE

Soil Cores.—Brookston silt loam, described in section E, page 68, because of its known susceptibility to sodium damage, was used. Three samples with slightly different aggregate stabilities, as indicated in table 55, were obtained fresh from the field. Three sets of cores were prepared in the standard manner except that lucite cylinders 1½ inches in diameter and 8 inches long were substituted for the 4-inch-diameter steel cylinders.

Soil columns were 5 inches high. Maximum head of liquid applied to the cores was approximately 3 inches. The head was never less than one-quarter inch.

Sampling and dosing.—Effluents from the tank receiving weekly doses of softener waste, as discussed above, and from a comparable tank receiving sewage only were obtained after each feed. Fifty ml of the proper effluent were added to each core and the volume which percolated in 15 minutes was measured. Any effluent then remaining, in excess of minimum head, was allowed to waste through the core before the next increment was applied. As the study progressed and the cores clogged, the volume of effluent added was reduced proportionately. The studies were continued until the cores became essentially clogged, which required about 6 weeks. At the conclusion of the

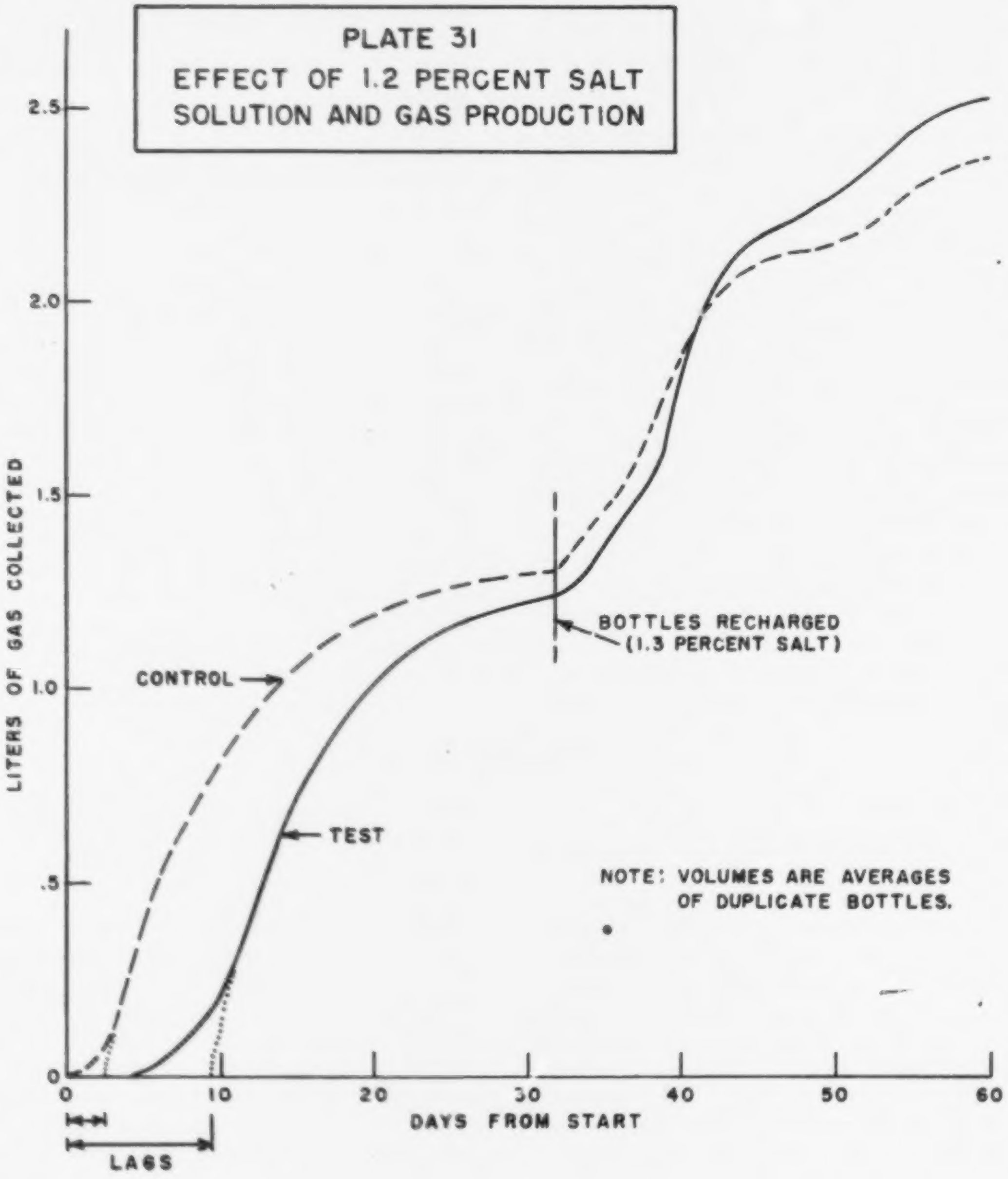


PLATE 31
EFFECT OF 1.2 PERCENT SALT SOLUTION AND GAS PRODUCTION

studies, the cores were dismantled and soil aggregate stability determined.

RESULTS

Chlorides in the salt effluent ranged from 7,000 down to 500 p. p. m. The concentration was highest immediately after a salt feed was made, gradually decreasing to about 1,000 p. p. m. by the end of the first day, and to about 500 p. p. m. before the next addition of waste a week later. Concentrations of chlorides in the normal effluent varied from about 50 to 100 p. p. m. The pH's of both effluents were similar, varying closely about a value of 7.2.

The percolation rate values at the start and at the end of the dosing periods and the aggregate analyses are shown in table 55. It will be noted that the salt effluent in every case caused less clogging than the normal effluent.

An example of the trend of core percolation rates with time is shown on plate 32. Despite the high probable sodium percentage in the salt effluents, its clogging effects were not noted as quickly as with the normal effluent. The rates compared on an equal solids basis show a similar trend.

In all three sets of cores, the water stability of aggregates from the normal effluent dosed cores was higher than the salt effluent, indicating that the brine effluent had caused more damage to the soil structure.

DISCUSSION

The results of this study are consistent with some agricultural studies. Magistad (45) points out that saline alkali soils containing a considerable amount of soluble salts are usually permeable because the salts maintain the soil colloids in a flocculated condition. As soluble salt concentration is reduced, the flocculation effect of the soil solution is reduced and ability to transmit water may be impaired. Plice (44) reported in a study of the soil-improving properties of different flocculators that sodium chloride proved to be a fairly efficient flocculator.

Although the phenomena are not fully understood, apparently high salt and high sodium concentrations can have a double-edged effect. A condition of high salts at pH less than 8.5 can create a flocculent condition resulting in pseudo-structure which is favorable for moisture movement. If the concentration is reduced, or if the pH is higher than 8.5, the salt can cause impaired permeability.

In the present study, the data indicate that percolation rates are maintained at a higher value under salt effluent than normal effluent, but that soil structure is more damaged by the salt effluent. In that soil aggregate water stability is an index of sustained permeability, such damage may be more important from the long-time viewpoint than short-time percolation behavior.

TABLE 55.—Percolation rates of cores dosed with effluents from a tank receiving softener salts and from a tank receiving normal sewage

Core set No.	Initial rate		Final rate		Aggregate stability	
	Salt ml/15 min.	Normal ml/15 min.	Salt ml/15 min.	Normal ml/15 min.	Salt Percent	Normal Percent
1	50. 0	48. 0	2. 0	1. 0	28. 6	33. 4
	49. 0	47. 0	1. 5	1. 0	28. 0	34. 1
	46. 5	47. 0	3. 0	1. 0	29. 5	35. 4
Mean	48. 5	47. 3	2. 2	1. 0	28. 7	34. 3
2	43. 2	41. 2	13. 5	2. 2	66. 7	73. 3
	42. 5	43. 0	6. 4	2. 3	66. 4	74. 2
	42. 8	41. 2	18. 4	1. 7	81. 6	78. 8
Mean	42. 8	41. 8	12. 8	2. 1	67. 2	73. 0
3	32. 6	35. 1	. 3	Tr.	43. 8	51. 9
	38. 6	37. 0	2. 0	Tr.	46. 8	52. 0
Mean	35. 6	36. 0	1. 1	Tr.	45. 3	52. 0

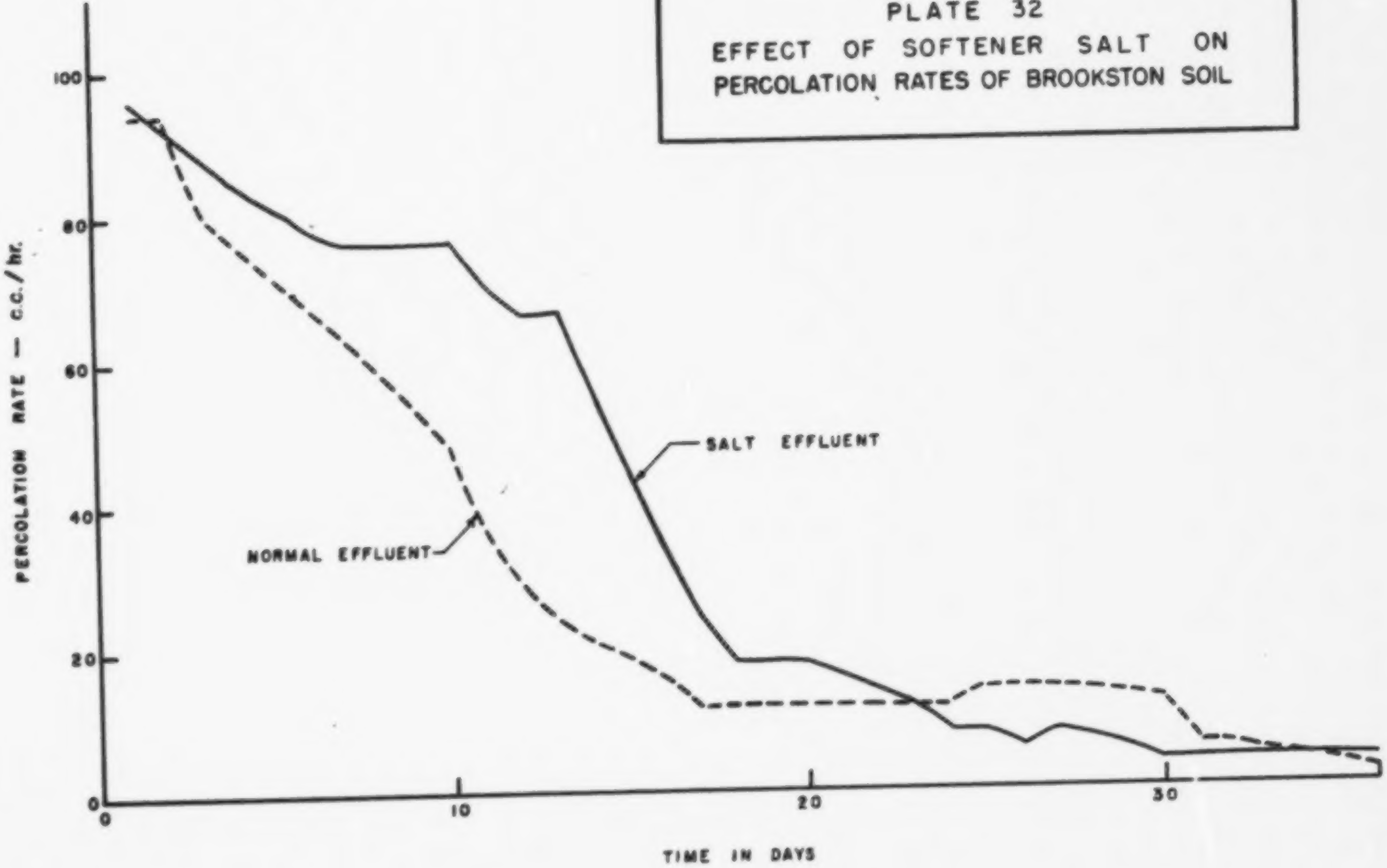


PLATE 32
EFFECT OF SOFTENER SALT ON PERCOLATION RATES OF BROOKSTON SOIL

SECTION G

Studies on Ground Garbage

INTRODUCTION

Since introduction of home garbage-grinders in the nineteen-thirties, the number in use reached roughly a quarter-million by 1949, and 1½ million by 1953. Although probably less than 10 percent of the household sewage disposal systems are currently involved, the rapid growth in garbage-grinder use forecasts its increasing importance in the general household waste pattern.

Previous studies dealing with treatment of ground garbage, with or without sewage, have concentrated on municipal problems. Some aspects so covered are also common to the individual household problem. In considering these, however, one should be mindful that garbage from the individual home, as well as sewage, reflects habits in a particular home, rather than a community composite. Wider variations in waste characteristics must therefore be expected.

From information given in several surveys (46, 47, 48, 49), a quantity of 0.65 pound per capita daily might represent average garbage production in American cities. Seasonal variation ranges from 151 percent of average during August to 70 percent during February (49).

Moisture content of garbage is reported as between 70 and 90 percent (50). Assuming 80 percent moisture, average production (dry) would amount to 0.13 pound per capita per day. For comparison, suspended solids production in community sanitary sewage is usually taken as 0.2 pound per capita per day (dry).

A comparison of garbage and sewage solids (50), is presented in table 56. It may be noted that garbage is higher in volatile matter, but lower in nitrogen, than sewage solids. The addition of ground garbage will, therefore, add considerably to the organic load on the septic tank system. The low nitrogen content warns of possible digestion difficulties.

Laboratory studies on digestion of ground garbage, with ripe sewage sludge as seed, have indicated difficulty, evidenced in low pH's and lag in gasification (51). However, in the same series of studies, mixtures of ground garbage and raw sewage sludge in ratios 1 : 0.67, 1 : 0.88, and 1 : 1.27, on a volatile matter basis, seeded with ripe sewage sludge, were successfully digested.

TABLE 56.—Comparison of garbage and sewage solids (percent)

Characteristic	Garbage	Sewage solids
Volatile matter	80-90	70-80
Ash	10-20	20-30
Grease	13-33	15-35
Nitrogen	0.4-1.5	4-6

Successful digestion of ground garbage, and of ground garbage plus raw sewage solids, seeded with ripe sewage sludge, under controlled pH conditions, have also been reported.

In one series of studies (52), wherein the ratios of daily garbage additions to daily raw sewage solids additions and to ripe seed sludge were very large, digestion was unsuccessful. This indicates need for sufficient seed material.

In sedimentation studies (53), mixtures of ground garbage and sewage settled rapidly, but supernatant liquor contained more total solids as compared with the sewage control. It has been reported that about 25 percent of dry garbage solids go into solution or nonsettleable suspension during grinding (54). It has also been reported that some 34 percent of garbage volatile solids go into solution or suspension upon grinding (55).

Summarizing from the literature, the indications are that solids load increases considerably and that supernatant liquors (effluents) are likely to contain more total solids, than when sewage only is treated; and that mixtures of ground garbage and sewage solids, in proportions approximating community production ratios, on a volatile matter basis, may be successfully digested provided there is sufficient ripe sewage sludge seed.

Septic Tank Studies

Laboratory

Experimental investigation of behavior of a home septic tank receiving ground garbage in addition to sewage was conducted at the Taft Sanitary Engineering Center from August 1947 to June 1948, a period of 10 months.

PROCEDURE

Experimental Plant.—Two identical 500-gallon single-compartment septic tanks were installed at the laboratory for this experiment. These were designated tank 9, to receive garbage and sewage, and tank 7, to receive sewage only as a control. Both tanks have been described in detail previously (1).

Feeding and Sampling.—Sewage was fed to each tank at a rate of 250 gallons per day, in accordance with the schedule outlined elsewhere (1). In addition, tank 9 received daily the garbage collected from two families, one having 3 persons, and the other 2. The garbage was passed through a household garbage-grinder before application to the tank. Each tank was seeded initially with 50 gallons of digested sewage sludge. Subsequent sludge additions were made, as indicated in table 57. Samples of raw sewage and effluent, collected at each feed, were composited for examination at 3- and 4-day intervals. Routine determinations on raw sewage and effluents included total and suspended solids, together with ash fractions, temperature, and pH.

RESULTS AND DISCUSSION

It may be noted in table 57 that, during the first 7 months of the 10-month run, the effluent from tank 9, receiving both garbage and sewage, contained slightly less suspended solids than that of control tank 7.[1] Considering that both received the same amount of sewage solids, the tank receiving garbage in addition operated at higher efficiency in suspended solids removal. Sludge accumulation rates would therefore be greater in the garbage tank during this time.

During the last 3 months of the experiment, effluents from both tanks increased considerably in suspended solids content. From 7-month averages of 118 and 131 p. p. m. for the garbage and control tank effluents, respectively, the concentrations rose to averages of 245 and 160 p. p. m. for the last 3 months. It will be noted that the garbage tank efficiency suffered the more. The drop in efficiencies accompanied rising temperatures and increasing digestion rates, a normal behavior. Digestion of the larger accumulation of volatile matter in the garbage tank no doubt increased tank agitation, resulting in relatively greater loss of solids from the garbage tank.

Garbage tank effluent pH's ranged between 7.3 and 7.5, essentially the same as those of the control

TABLE 57.—Sludge and effluent solids data

Date	Digested sludge added at start of period	Raw sewage fed	Effluent solids (ppm)								Ratio SVS/SS	
			Total		Total volatile		Suspended		Suspended volatile			
			Control	Garbage	Control	Garbage	Control	Garbage	Control	Garbage	Control	Garbage
	Gallons	*Gallons*										
Aug. 20 to Sept. 23, 1947	50. 0	7, 490	642	716	218	292	109	103	80	84	0. 73	0. 82
Oct. 11 to Nov. 8, 1947	200	7, 580	716	721	231	217	123	123	75	79	. 61	. 64
Nov. 24, 1947 to Feb. 15, 1948	300	18, 280	772	819	199	217	128	118	93	92	. 73	. 78
Feb. 23 to Mar. 28, 1948	....	6, 410	826	767	250	234	173	126	99	86	. 57	. 68
Mar. 30 to June 28, 1948	62. 5	19, 420	749	853	236	301	160	245	92	151	. 58	. 62
Weighted average	....	....	747	799	223	256	140	159	89	108	. 64	. 68

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[1] Preliminary analysis of results from an additional 2¼ years of operation of garbage and nongarbage tanks during February 1949 to May 1951 indicates that, on the average, effluent from tank receiving garbage and sewage contains about the same suspended solids concentration as that of the control tank receiving sewage only.

tank. This tank was well-seeded with digested sludge, contributed by the accelerated additions. In practice, the ratio of digested sludge to raw garbage and sewage solids might be less. Consequently, the value of adequate initial seeding should not be overlooked.

It may also be noted in table 57 that the garbage tank effluent tended toward slightly larger proportions of volatile suspended matter than did the control.

Field

INTRODUCTION

During the period April to July 1951 field examinations on 39 home septic tank-soil absorption systems, 16 of which received ground garbage, were made in Duval County, Fla. This area (near Jacksonville) offered active support and cooperation of county and State health departments, systems of the same age operating with and without ground garbage loadings, all under similar climatic and soil conditions. Analyses of the data obtained have not been completed at this time. However, from analysis thus far, certain facts are evident and of interest. The complete analysis will appear in the final report on this project.

PROCEDURES

An engineer-laborer team obtained system histories from the local health department and from the householder, including time in service, number of residents, number and types of plumbing units discharging to the tank, and other information related to system use. The tank was opened, accumulations of sludge and scum measured, sludge and supernatant pH determinations made, and air, tank, and ground temperatures recorded.

RESULTS AND DISCUSSION

The accumulation of sludge and scum in tanks receiving ground garbage was compared with that of tanks receiving sewage only, both in the Duval County area and with that of other tanks receiving sewage only, surveyed previously in other areas in the United States. These comparisons are shown in table 58.

The average accumulations found in the nongarbage tanks in the Duval County area are essentially the same as those found in nongarbage tanks previously inspected in other areas in the United States.

TABLE 58.—Comparison of sludge and scum accumulations of garbage and nongarbage septic tanks

Type	Number of systems examined	Average tank capacity (gallons)	Average time in service (years)	Average rate of accumulation ft.^{3}/person/year		
				Sc+Sl	Sl	Sc
Garbage	16	751	3.22	3.33	1.82	1.51
Nongarbage (Duval County) [a]	[a] 19	613	3.66	1.88	1.39	.49
Nongarbage (other areas 3 to 4 years in service)	33	550	3.36	1.94	1.46	.48

[a] Data from 4 atypical nongarbage tanks discarded.

The average sludge plus scum accumulation in the garbage tanks was 77 percent larger than in the nongarbage tanks in the Duval County area. The major increase was in the scum accumulation, averaging approximately 210 percent, while the sludge accumulation increase averaged 31 percent. Studies on the variation in these are not yet available.

Supernatant pH's ranged from 6.0 to 7.5, and sludge pH's from 6.0 to 7.1 in the garbage tanks, with medians at 6.5 and 6.8, respectively. For the nongarbage tanks, the ranges were 6.3 to 7.3 for supernatant, and 6.4 to 7.4 for sludge, with medians at 6.8 and 6.9, respectively. As a whole, these appear slightly lower than might be expected, particularly on the nongarbage tanks. A relatively high sulphate water was supplied these homes. The tendency for the garbage tanks to persist in lower pH's than nongarbage tanks after some 3½ years of operation at relatively high temperatures is evident. Supernatant liquor temperatures taken during the survey averaged 82° F.; those of the ground, 76° F. In more than half the cases, home laundering wastes were not discharged through the tanks, which would result in some loss in alkalinity. Further analysis of data is in progress.

Soil Clogging Studies

Laboratory

INTRODUCTION

Studies of the relative clogging effect of effluent from a septic tank receiving ground garbage in addition to normal household sewage, as compared to normal household sewage without garbage added, were incorporated into soil core studies discussed in a previous report (2). Data on two series of soil cores showed a definite trend for the sewage plus garbage effluent to cause more clogging. The soil used was a heavy reddish-brown clay more recently identified from soil survey reports as Miami clay loam. The two series of cores differed in the density of packing, so that they represent two different permeability conditions, or for practical purposes, two different soils.

PROCEDURES

Similar studies of ground garbage were incorporated into three series of cores in section E of this report. The cores essentially represent three different soils, Genesee silt loam packed to two different densities, which is reflected in different percolation rates, and Genesee loam. The soils and experimental procedures are described in the original description of the studies, pages 64 to 65.

RESULTS AND DISCUSSION

Data concerning the relative effect of garbage and nongarbage effluents on soil clogging from all 5 series are shown in table 59. The cores from each soil type having initial percolation rates of the same magnitude were considered as pairs to which different treatments were subsequently applied, thus giving 11 comparisons.

It may be noted that, except for one pair of the Miami cores, the paired initial rates were not far different. Also, it will be noted that any differences that did exist were not related to later treatment. In 6 cases, the cores that were later dosed with garbage effluent had the higher initial rates, while in 1 case the intial rates were the same. The over-all mean of the initial rates of cores later dosed with nongarbage effluent was 25.3 ml/hr., those later dosed with garbage effluent, 28.2 ml/hr. Disregarding the 1 Miami pair, the means are 20.1 and 20.2 ml/hr., respectively, which are not significantly different.

After the cores had been dosed for from two to three months, differences in rates between the paired cores developed. In 10 out of the 11 core pairs, the cores dosed with garbage effluent reached lower percolation rates after equal time of dosing. A similar trend is apparent at a point where equal amounts of suspended solids had been added. On the time basis, the average clogged rates were 4.7 and 3.9 ml/hr., and on the solids basis, 6.2 and 4.8 ml/hr., for the nongarbage and garbage cores, respectively. Disregarding the 1 Miami pair, the differences in averages are even greater.

If the clogged rates are converted to a percent of original rate basis, at equal times of dosing the nongarbage core rates reduced to 23.9 percent, while the garbage core rates reduced to 19.0 percent, of the original rates. At equal solids added, the respective rates were 30.5 and 22.1 percent.

The increase in area which would be necessary to enable a garbage core to absorb the same amount of effluent as a nongarbage core, at a point where both had received equal amounts of suspended solids (or equal volumes of effluent), may be estimated from the inverse ratio of their clogged percolation rates on an equal solids applied basis. Statistical analyses of this type of data from table 49 have been made. The garbage cores would require an average increase in area of about 11.8 percent, with a standard deviation of 21.2 percent.

Field

The field examinations on 39 home septic tank-soil absorption systems in Duval County, Fla., included an examination of the soils.

PROCEDURE

Sections of absorption trenches were opened at each system examined. Auger hole percolation tests were made at each site in an unaffected soil area and soil core percolation tests were made on samples taken from used and unused sections of the trenches. The samples were subsequently shipped to Cincinnati for grease and organic matter content determinations.

RESULTS AND DISCUSSION

Sandy soils having excessively fast percolation rates prevailed in the installations inspected, tending to minimize any differences in soil behavior attributable to garbage and nongarbage effluent.

Preliminary analysis of data indicates that, on the average, percolation rates of soil cores taken from used trench sections of garbage systems were slower than those from nongarbage systems. A slightly greater increase in organic matter content was noted in the soils from garbage systems. No measurable differences in grease content were found.

TABLE 59.—Effect of garbage and nongarbage effluents on soil core clogging

Soil type	Percolation rates									
	Original		After dosing cores equal lengths of time				After equal amounts of suspended solids had been added			
	Non-garbage	Garbage	Non-garbage	Garbage	Non-garbage	Garbage	Non-garbage	Garbage	Non-garbage	Garbage
	Ml./hr.		Ml./hr.		Percent of original		Ml./hr.		Percent of original	
Miami clay loam No. 1	29.0	28.4	5.3	4.5	18.3	15.8	5.6	4.5	19.3	15.8
	77.5	107.7	6.6	6.8	8.5	6.3	10.5	11.9	13.5	11.0
Miami clay loam No. 2	16.3	14.7	4.0	3.9	24.5	26.5	6.4	4.2	39.3	28.6
	17.1	15.4	5.1	3.6	29.8	23.4	10.9	3.4	63.7	22.1
Genesee silt loam No. 1	18.5	16.6	6.9	3.9	37.3	23.5	9.0	5.4	48.6	32.5
	9.4	10.6	3.4	3.0	36.2	28.3	3.5	3.2	37.2	30.2
Genesee silt loam No. 2	31.0	32.0	3.8	3.0	12.3	9.4	4.1	3.8	13.2	11.9
	27.0	29.0	4.1	2.9	15.1	10.0	4.2	3.5	15.6	12.1
	25.0	27.0	4.1	3.8	16.4	14.1	4.0	4.9	16.0	18.1
Genesee loam	15.2	16.0	5.0	3.9	32.9	24.4	5.5	4.5	36.2	24.1
	12.4	12.4	3.9	3.4	31.4	27.4	4.1	4.1	33.1	33.1
Mean	25.3	28.2	4.7	3.9	23.9	19.1	6.2	4.8	30.5	22.1

SECTION H

Studies on Synthetic Detergents in the Septic Tank-Soil Absorption System

INTRODUCTION

The increasing use of synthetic detergents (syndets) in the home raises the question of effect of syndets on household septic tank and soil absorption field operation. In the past 20 years or so, sales have risen from nothing to over 1½ billion pounds a year (64, 65).

Based on ionization of the active agent in water, syndets are generally classified as anionic, cationic, or nonionic. The bulk of syndets marketed for household use fall into the anionic group. According to Eliassen (64), only anionic syndets need be considered in municipal sewage treatment processes, as their use far exceeds any others.

Except for one study (66), reported below, the literature reviewed (67 through 81) deals with the question in relation to municipal sewage treatment. Opinion is divided as to the extent of an actual problem. Some investigators advance data to show that damage is being done, while still others indicate that no actual problem has arisen, or is even likely to arise.

Fuller (66) observed the effect of eight household type and three industrial type syndets on sewage digestion processes related to the functioning of a septic tank. The study was conducted in a series of two-quart jars, using a concentration of 100 p. p. m. for all syndets and additional tests with concentrations of 10 p. p. m. for the industrial types. Test jars were compared to control jars on the basis of turbidity, scum and sludge build-up, settleable solids, total bacteria counts, numbers and types of coliform bacteria, ammonification, nitrate content, and hydrogen sulfide production. Fuller indicated that, within the limits of the experimental conditions, household-type syndets would not interfere with the proper functioning of septic tanks.

The question, as it pertains to the home septic tank-soil absorption system, concerns the effect of substitution of synthetic detergents for soap on (*a*) efficiency of a septic tank, (*b*) biological activity, and (*c*) soil absorption characteristics.

In dealing with these topics, the physical tank aspects were studied in a full-scale septic tank; biological activity, in a series of bottle experiments; and soil clogging effects, in laboratory soil core and field experiments.

Septic Tank Studies

INTRODUCTION

In that sewage used throughout the household sewage disposal studies derives from a residential area, it can be assumed that it contains residual syndet. If additional syndet, say an amount representing that used for the family wash, were added to the residual, a somewhat more severe loading condition would be created. If no trouble were to develop under these conditions, it would seem likely that no trouble would develop under normal household usage.

PROCEDURES

An informal survey of home laundry habits of several workers at the Taft Sanitary Engineering Center indicated that more syndet is used with automatic washers than with nonautomatic. For automatic washers, a common usage was about one cupful, weighing some 85 grams, per load.[2] Some families using automatic washers laundered on one day only, while others spread the laundering over several days through the week.

Considering that a slug dose of chemicals may be more harmful to a biological process than the same quantity applied in gradual doses, it was decided to simulate the four-load Monday morning wash waste pattern to approximate a maximum loading condition.

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[2] Eighty-five grams per load would be about ¾-pound per 4-load wash; ¾-pound in a 500-gallon tank would amount to a concentration of about 180 p. p. m., assuming complete mixing.

Experimental Plant.—The experiment was conducted in two single-compartment 500-gallon septic tanks operated at the laboratory under controlled conditions. One of these, tank 6, served as the control, receiving sewage only, while the other, tank 5, received sewage and syndet. These tanks had performed equally well in past experiments on sewage loadings, with suspended solids removal for tank 5 averaging 60 percent, and tank 6, 59 percent (1).

Feeding and Sampling.—Each tank received 250 gallons of sewage per day, applied in 8 scheduled feeds. The quantity and time of each feed was varied according to the water use pattern followed in previous experiments. The tanks were operated identically, except that tank 5 received 85 grams of an anionic syndet in each of its first four sewage feeds Monday mornings. A commercial product containing 40 percent of the anionic syndet, sodium alkyl aryl sulfonate, was used for this experiment. The 85 grams were thoroughly stirred into the charge of sewage before dosing to the test tank.

After each addition of raw sewage, effluent from each tank was collected in a 55-gallon drum. A sample was taken from each drum and temperature and pH noted. Routine determinations on biweekly composites included total and suspended solids, including ash fractions. Effluent grease analyses on biweekly composites, one week per month, were made, according to Standard Methods (82). Effluent suspended solids determinations were made on the eight individual feeds on Mondays. Sludge measurements were made weekly, and once each month samples of sludge were taken from the top, middle, and bottom of the sludge accumulation in each tank, to determine the presence or absence of biological activity. A visual check was maintained to note any unusual activity.

The experiment ran for 27 weeks, with the first syndet addition on January 28, 1952, and the final feed August 1, 1952.

RESULTS AND DISCUSSION

Suspended Solids.—Results of the weekly suspended solids removals and total sludge accumulated are presented on plate 33. Both tanks followed the seasonal pattern of consistently high solids removals and rapid accumulation of sludge during cold months, followed by decrease in sludge volume and deterioration in effluent quality during the warm months. The seasonal upset was more severe in control tank 6 than in test tank 5.

During the experiment, 31,370 gallons of raw sewage, averaging 452 p. p. m. suspended solids, were fed each tank. The weighted average suspended solids content of the test tank effluent was 153 p. p. m. as compared with 195 p. p. m. for that of the control tank, representing percentage suspended solids removals of 66 and 57 for the test and control tanks, respectively.

Statistical evaluation of the differences in the paired weekly effluent results indicates that the difference in performance is significant at the 0.1 percent level.

Whether the improved performance of the test tank was due to the addition of the syndet is questionable. In the first year of these studies, five 500-gallon single-compartment tanks, including tanks 5 and 6 concerned here, registered average suspended solids removals ranging between 59 and 65 percent. Consequently, the average 57 and 66 percent removals developed during this test might represent opposite sides of a normal deviation among tanks of this type. However, it is clearly demonstrated that the detergent used did not interfere with the suspended solids removal performance of the tank.

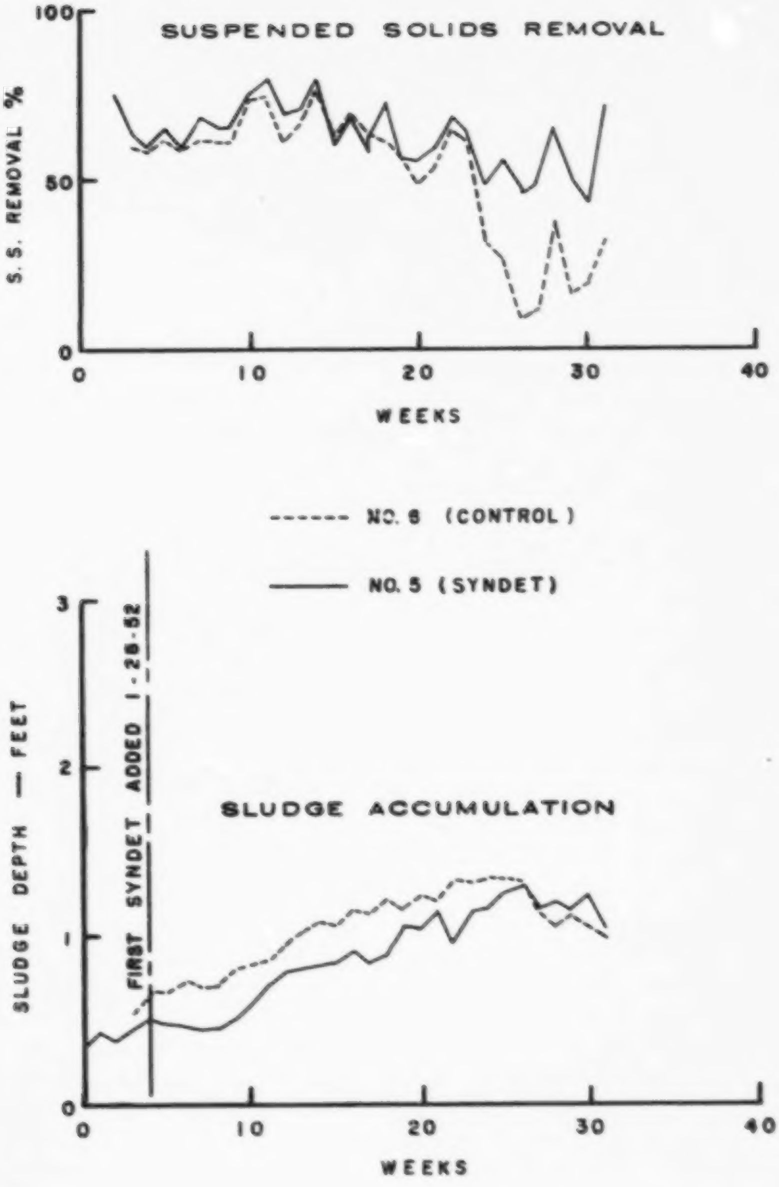
Effluent suspended solids during each of the four syndet-sewage feeds and remaining four sewage feeds, Mondays, indicated little or no difference in relative performance on that day as compared with overall performance. Weighted averages for the 27 Mondays were 155 and 195 p. p. m. effluent suspended solids for test tank and control, respectively, as against the overall 153 and 195 p. p. m. concentrations previously indicated.

Biological Activity.—At intervals of approximately one month, three small samples of sludge were taken from each tank to determine whether they were biologically active. The sampling points were, approximately 3 inches below top of sludge, middepth of the sludge blanket, and 3 inches from the tank bottom.

For each sample, a test tube was prepared in which 10 ml. of the sludge were mixed with 90 ml. of raw sewage. A smaller test tube was then inverted in the mixture with all air expelled from it, an arrangement similar to that used in bacteriological presumptive tests for coliform organisims. Accumulation of gas in the inverted tube was taken as evidence of biological activity.

PLATE 33

SYNDET TANK EXPERIMENT



The tubes were examined at intervals, noting the day on which the gas first appeared. These results are given in table 60. An approximation was made of the total volume of gas collected.

TABLE 60.—Biological activity, in syndet sludge

Month sample was taken	Number of days after start of test that first gas was noted—					
	3 inches below top of sludge		Middle of sludge		3 inches from bottom of tank	
	Test	Control	Test	Control	Test	Control
February	1	2	1	2	1	2
March	1	1	1	1	2	1
April	17	10	17	4	2	4
May	22	7	22	7	2	2
June	20	7	10	4	4	4
July	10	3	10	3	3	3

These data demonstrate normal biological activity in all of the samples taken near the bottom of the tank. However, at middepth and near top of sludge, the microbiota seem to be more active in the control than in the test tank.

Another indicator of the intensity of biological activity taking place in a tank is the proportion of volatile matter in the effluent suspended solids. Effluent solids low in volatile matter are generally considered to be more thoroughly digested than those higher in volatile matter.

Table 61 contains the results of the weekly suspended solids determinations, showing the proportion of volatile suspended solids to suspended solids in the effluents. The suspended solids in the syndet tank averaged 77 percent volatile, as compared with 74 percent in the control tank.

Statistical examination of the individual weekly differences in the ratios indicates that the difference in volatile matter content is significant at the 8-percent level. The data do not, therefore, demonstrate a conclusive difference in the effluent, although the possibility is suggested.

Several factors indicate that normal anaerobic processes were slightly inhibited in the test tank. The comparisons on biological activity and volatile matter in effluent solids can be interpreted in that manner. The improvement in suspended solids removal previously noted could result from a reduced rate of digestion and gas production. It has been demonstrated several times in these studies that, when digestion is slow, sedimentation in a septic tank is more efficient than during periods of rapid digestion. As mentioned earlier, the seasonal upset was not so severe in the test tank as it was in the control, nor so severe as that registered when the test tank was operated on sewage feeds during the first year of these studies.

Although no one of these factors taken individually can be considered conclusive, the sum of the evidence indicates that the rate of digestion was reduced, although not seriously.

Grease.—Results of grease analyses are presented in table 62. These figures indicate that the effluent from the test tank contained slightly more grease than that from the control tank. However, it is doubtful that this slight difference in grease content, 5 p. p. m. could have any appreciable effect on the absorption characteristics of soil. The test tank averaged 58 percent grease removal, as compared with 61 percent for the control tank.

TABLE 61.—Proportion of volatile matter in effluent suspended solids

Week	Syndet tank 5			Control tank 6		
	S. S. (p. p. m.)	V. S. S. (p. p. m.)	Ratio V. S. S./S. S. (percent)	S. S. (p. p. m.)	V. S. S. (p. p. m.)	Ratio V. S. S./S. S. (percent)
1	127	104	82	140	108	77
2	114	86	75	119	87	73
3	134	115	86	157	135	86
4	150	118	79	166	142	86
5	167	143	86	187	158	84
6	175	156	89	188	155	82
7	133	84	63	154	98	64
8	119	100	84	153	106	69
9	124	95	77	146	111	76
10	137	110	80	151	127	84
11	163	130	80	172	139	81
12	136	107	79	139	118	85
13	145	108	74	162	123	76
14	130	94	72	189	147	78
15	209	138	66	211	144	68
16	183	147	80	213	173	81
17	145	130	90	162	130	80
18	171	139	81	184	148	80
19	216	169	78	226	126	56
20	170	125	74	229	164	72
21	203	136	67	339	248	73
22	166	128	77	280	203	72
23	163	124	76	278	203	73
24	144	108	75	266	176	66
25	152	90	59	256	155	60
26	168	105	62	242	149	62
27	134	115	86	320	192	60
Average			77			74

TABLE 62.—Grease in effluents (p. p. m.)

Composite sample from		Grease[1]			Average to date (weighted)		
Month	Days	Raw sewage	Control tank 6	Syndet tank 5	Raw	No. 6	No. 5
February	4, 5, 6	95	20	34			
Do	7, 8	101	37	38	97	27	35
March	3, 4, 5	162	73	72	122	44	49
Do	6, 7, 9	256	62	71	157	49	55
March-April	31, 1, 2	201	60	65	167	51	57
April	3, 4	168	66	64	167	53	58
May	5, 6, 7	200	63	77	172	54	61
Do	8, 9, 10	152	78	63	169	57	61
June	9, 10, 11	134	55	86	165	57	64
Do	12, 13	78	49	56	159	57	63
July	21, 22, 23	90	64	65	153	57	64
Do	24, 25	77	55	43	148	57	62

[1] Ether soluble.

Bottle Digestion Studies

INTRODUCTION

Investigation of the effect of syndets on anaerobic digestion of a sewage and ripe sludge mixture was carried out in three steps: Several concentrations of a commercial anionic syndet; several household brand syndets at a concentration reflecting usage level exceeded by only 5 percent of the cases; and several household brand syndets at a concentration reflecting average usage.

Several Concentrations of a Commercial Anionic Syndet

PROCEDURES

A commercial anionic syndet containing 40 percent sodium alkyl aryl sulfonate, the same product used in the tank experiment reported above, was used. This product was added in amounts sufficient to produce active agent concentrations of 100, 150, 200, 250, 300, and 500 p. p. m. in a sewage-ripe sludge mixture. The whole product concentrations were, therefore, 2½ times as large.

The 6 test mixtures and 3 controls were set up in 10-liter glass bottles, each equipped for gas collection in an inverted 500 ml. dispensing burette containing a saturated sodium chloride solution. Test mixtures contained 8 volumetric parts raw sewage to 1 of ripe septic tank sludge, plus sufficient syndet to provide the various concentrations above mentioned. The first control contained 8 parts sewage and 1 ripe sludge, only; the second, 8 parts tapwater and 1 ripe sludge; and the third, 8 parts tapwater, 1 ripe sludge, and 300 p. p. m. syndet active agent.

Solids, surface tension, and pH determinations were made on the mixtures at the start and finish of the experiment. Daily observations were made on the amount of gas produced.

RESULTS AND DISCUSSION

The volume of gas produced during the first 45 days of the experiment, plotted against time, is shown in plate 34. There was lag in the start of gas production at all concentrations. After 10 days, appreciable gas developed at all but the 500 p. p. m active agent concentration, which failed to produce gas during 88 days. It may be noted that at 150 p. p. m. active agent concentration, gas production exceeded that of the control. At concentrations of 200 p. p. m. and above, there was significant reduction in gas production as compared with the control. At 100 p. p. m. active agent, the amount of gas produced was more than that produced in the 200 p. p. m. and greater concentrations, but less than that of the control. No measurable gas was produced from the tapwater plus ripe sludge control. A small amount of gas was produced in the tapwater plus ripe sludge plus 300 p. p. m. active agent control, possibly derived from decomposition of the syndet product.

Surface tension, pH, and gas production data are shown in table 63. Solids determinations reflected difficulties with sampling techniques, and are not shown.

TABLE 63.—Surface tension, pH, and gas production

Bottle No.	Syndet (p. p. m.)		Surface tension (dynes/cm.)		pH		Gas produced in 88 days	
	Active agent	Whole product	Start	Finish	Start	Finish	Cubic centimeters	Percent of control No. 7
1	100	250	42. 4	44. 8	7. 4	7. 3	1, 707	77
2	150	375	43. 1	46. 1	7. 5	7. 4	3, 168	142
3	200	500	36. 8	43. 7	7. 5	7. 5	1, 392	62
4	250	625	36. 2	42. 8	7. 5	7. 6	1, 312	59
5	300	750	34. 1	42. 2	7. 5	7. 7	814	36
6	500	1, 250	34. 0	39. 6	7. 4	7. 7	0	0
7 [1]	0	0	52. 0	54. 2	7. 6	7. 5	2, 228	100
8 [2]	300	750	34. 6	41. 9	7. 5	7. 7	240	11
9 [3]	0	0	57. 2	56. 7	7. 4	7. 4	0	0

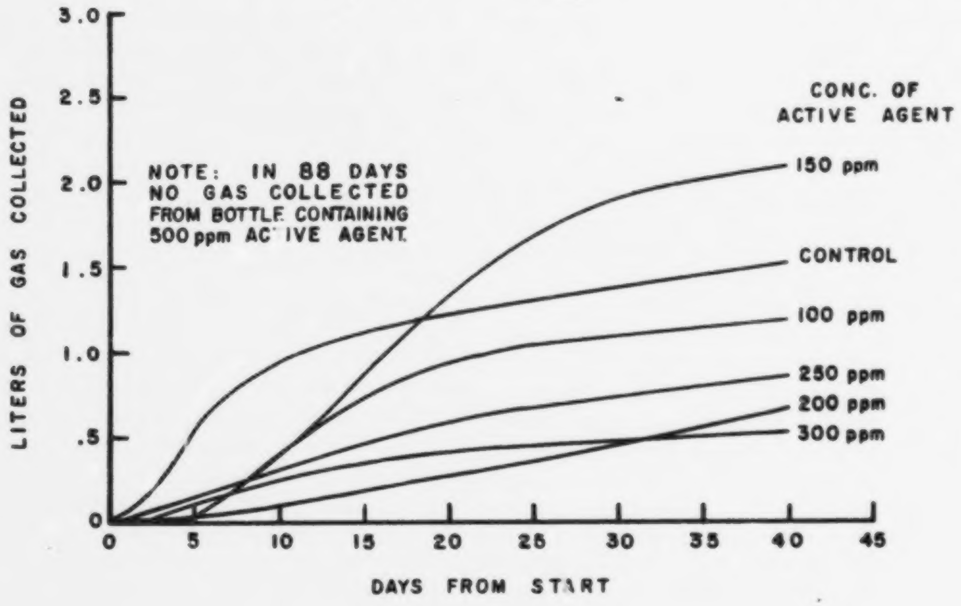
[1] Sewage and ripe sludge.

[2] Tapwater, ripe sludge, and syndet.

[3] Tapwater and ripe sludge.

PLATE 34

GAS PRODUCTION — SYNDET
40% SODIUM ALKYL ARYL SULFONATE



Because of the apparently unusual behavior at the 150 p. p. m. active agent concentration, the experiment was repeated.

Repeat Experiment

PROCEDURES

The only major changes in the repeat series from procedures used in the first were the substitution of a 50 p. p. m. active agent concentration for the previous 500 p. p. m. in the series of 6 test concentrations, and the shortening of the run to 70 days, May to July 1952.

RESULTS AND DISCUSSION

The relative trends in gas production were well established during the first 45 days. These trends are shown on plate 35. These data confirm the suspicion that the behavior of the previous 150 p. p. m. concentration bottle was erratic, and confirm the results obtained at other concentrations previously.

Although slight lags developed, there was no appreciable interference with gas production at syndet active agent concentrations of 150 p. p. m. (equivalent to 375 p. p. m. whole product) or lower. At active agent concentrations of 200 p. p. m. (equivalent to 500 p. p. m. whole product) and greater, the rate of gas production was retarded. Concerning the controls, some gas was produced in both tapwater-ripe sludge controls; about 576 cc. without syndet and 235 cc. with syndet (300 p. p. m. active agent) during the 70 days, but the volumes produced were very small as compared with those of the bottles containing sewage.

Several Household Brand Syndets—Using More-than-Average Quantities

INTRODUCTION

The previous bottle experiments indicated that the "twilight" zone separating consequential interference from noninterference with anaerobic digestion of an eight-to-one volumetric mixture of sewage and ripe septic tank sludge was between 150 and 200 p. p. m. active agent concentrations for one anionic type commercial (40 percent sodium alkyl aryl sulfonate) syndet. The equivalent whole product concentrations would be 375 and 500 p. p. m., respectively.

Concurrently with the above-mentioned experiments, a survey of Taft Sanitary Engineering Center families was made to obtain information on average and variations in syndet usage. For a small sample of 9 families laundering at home, the average syndet (whole product) usage was about 11 ounces per family per week for laundering alone, and 6 ounces per person per week for all purposes, including laundering; also that in 5 percent of the cases the usages would exceed 21 and 10 ounces, respectively.

A theoretical concentration pattern for a 500-gallon tank was then computed on the basis of the above usages, assuming a 4-person family, laundering on 1 day weekly, flow at 39 g. p. c. d. and complete mixing. The recurring weekly pattern for average usage was a peak day (washday) at 264 p. p. m. whole product, reducing to 110 p. p. m. in 7 days, roughly averaging 187 p. p. m. Similarly, usage of amounts of syndet product which would be exceeded by 5 percent of the cases resulted in a peak day at 476 p. p. m. whole product, reducing to 168 p. p. m. in the weekly cycle, roughly averaging 322 p. p. m. In the absence of better information, these values served as a rough guide in setting up the remaining experiments. They should not be considered as indicative of the general pattern.

Considering the previously indicated 375 to 500 p. p. m. whole product "twilight" zone between interfering and noninterfering concentrations for one commercial syndet, it is seen that the theoretically developed tank concentrations fall in the noninterference zone for average syndet usage, but extended into the "twilight" zone for the higher usage. In view of this, and in order to expose the effect, if any, of various syndet product builders, an experiment to reflect the higher syndet usage and a variety of household syndets was undertaken.

PROCEDURES

Seven household syndets, obtained at a local grocery store, were used. Five of the brands are listed as the alkyl aryl sulfonate type (65). No type identification was available for the remaining two. The volatile content of the seven syndets ranged from 31 to 41 percent; in distilled water, the pH's of 5 of the products ranged from 9.1 to 9.4, and 6.5 and 7.2 for the other 2.

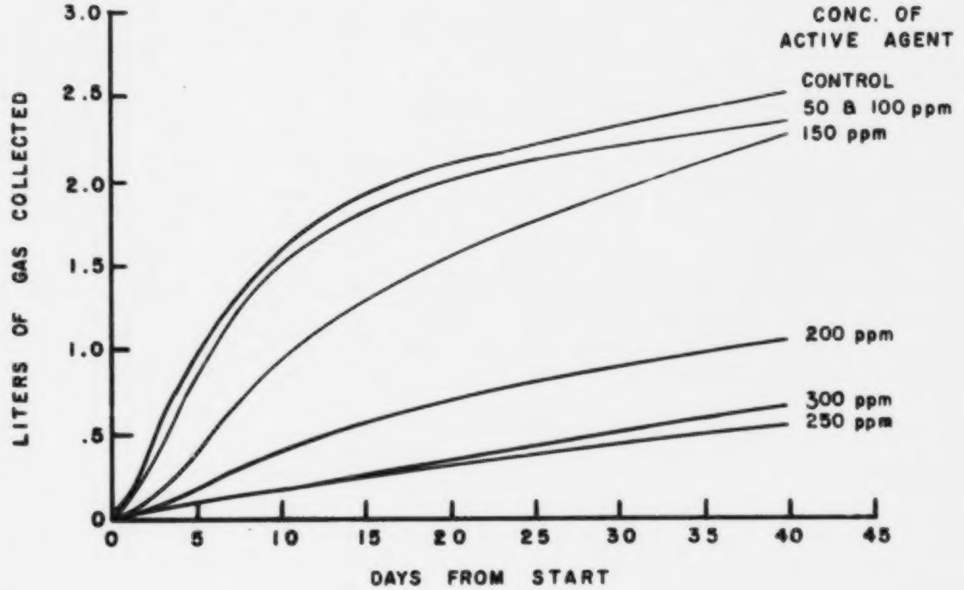
Into each 10-liter serum bottle, set up in duplicate for each brand, was placed a mixture of 3.35 gms syndet (whole product), 1.250 liters ripe septic tank sludge, and 5.590 liters of fresh sewage, resulting in a syndet (whole product) concentration of about 490 p. p. m. After 24 hours, the mixtures were diluted to 10 liters with fresh sewage, so that the second day concentration was about 335 p. p. m. These concentrations approximate the theoretical upper usage tank concentrations, 476 and 322 p. p. m., above mentioned. Duplicate controls were similarly prepared, except that no syndet was added. After dilution, the bottles were connected to gas-collection apparatus described in earlier experiments. Temperatures, pH, and solids determinations were made at the start and end of the 28-day period of digestion, and gas accumulations were recorded at intervals throughout the experiment.

RESULTS AND DISCUSSION

Of the two parameters, gas production and reduction in volatile matter commonly used to trace the course of anaerobic digestion, the former is used here as the more reliable under the circumstances of this experiment.

PLATE 35

GAS PRODUCTION — SYNDET — (REPEAT)
40% SODIUM ALKYL ARYL SULFONATE



The volumes of gas collected from test bottles and controls are graphed on plate 36. In table 64, the total volumes of gas produced, together with their percentage comparison with the control, are shown. Because of erratic results and suspected gas leakage on bottles 1 and 5, the two were re-run against a new control, using the same methods as before. These results are also shown on plate 36 and in table 64.

It may be noted that several of the brands noticeably interfered with normal digestion at syndet usages which would be exceeded by only 5 percent of the cases. Because mixed results developed at this level, the experiments were extended to investigation of behavior at concentrations reflecting use of average quantities of syndet.

TABLE 64.—Total gas production—more-than-average syndet usage

Bottles with syndet No.	Days digested	Gas collected [1]	
		Cubic centimeters	Percent of control
1	28	2, 107	93
2	28	1, 375	61
3	28	1, 626	72
4	28	2, 032	90
5	28	1, 580	70
6	28	2, 369	104
7	28	1, 566	69
Control	28	2, 267	100
Repeat 1	28	1, 741	85
Repeat 5	28	1, 703	83
Repeat control	28	2, 048	100

[1] Average of duplicates, except initial run Nos. 1 and 5, which are singles.

Several Household Brand Syndets—Using Average Quantities

PROCEDURES

The syndets and procedures used were the same as in the previous experiment, the only change being that here the syndets were added in amount sufficient to provide a first-day concentration of 250 p. p. m. of the whole product, and after dilution with raw sewage 24 hours later, a concentration of 175 p. p. m. These concentrations approximate the theoretical tank concentrations, 264 and 187 p. p. m., previously computed as a four-person family washday concentration in a 500-gallon tank, and the weekly average, respectively, based on average syndet usage.

RESULTS AND DISCUSSION

The gas collected is graphed on plate 37. In table 65, the total volumes of gas produced, together with their percentage comparison with the control, are shown. Because of suspected operational difficulties with apparatus for bottles containing syndets Nos. 3 and 5, these were re-run. The results of these are also shown on plate 37 and in table 65. It is evident that none of the seven brands interfered seriously with normal digestion at average syndet usages.

TABLE 65.—Total gas production—average syndet usage

Bottles with syndet Number	Days digested	Gas collected [1]	
		Cubic centimeters	Percent of control
1	31	1, 043	84
2	31	1, 070	86
3	31	1, 148	92
4	31	1, 146	92
5	31	823	66
6	31	1, 236	99
7	31	1, 081	87
Control	31	1, 243	100
Repeat 3	29		89
Repeat 5	29		96
Control	29		100

[1] Average of duplicates, except initial run No. 3, which is a single.

Laboratory Soil Studies

INTRODUCTION

Laboratory soil clogging studies of soaps and syndets were made in three phases: first, their effects when in tap water solutions; secondly, when in laundry waste waters; and thirdly, the effects of increased concentrations in septic tank effluent.

The soap and syndet used were obtained at a local grocery store. The syndet was of the anionic, alkyl aryl sulfonate type. In all of the following experiments, concentrations of soap or syndet in dosing solutions were kept within 50 to 500 p. p. m. total product concentration.

PREPARATION OF SOIL CORES, DOSING

Soils were collected and cores prepared in the standard manner as previously described, and tapwater was run through the cores until relatively

PLATE 36

GAS PRODUCTION — SYNDET
INITIAL CONC. 490 ppm. (WHOLE PROD.)
CONC. DURING COLLECTION 335 ppm.

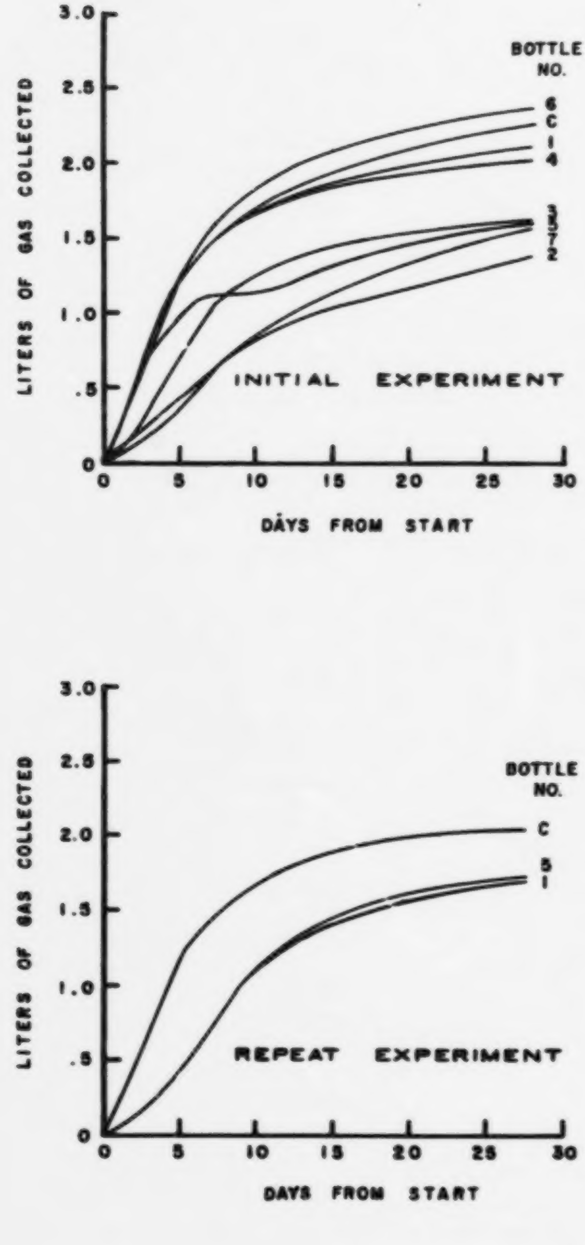
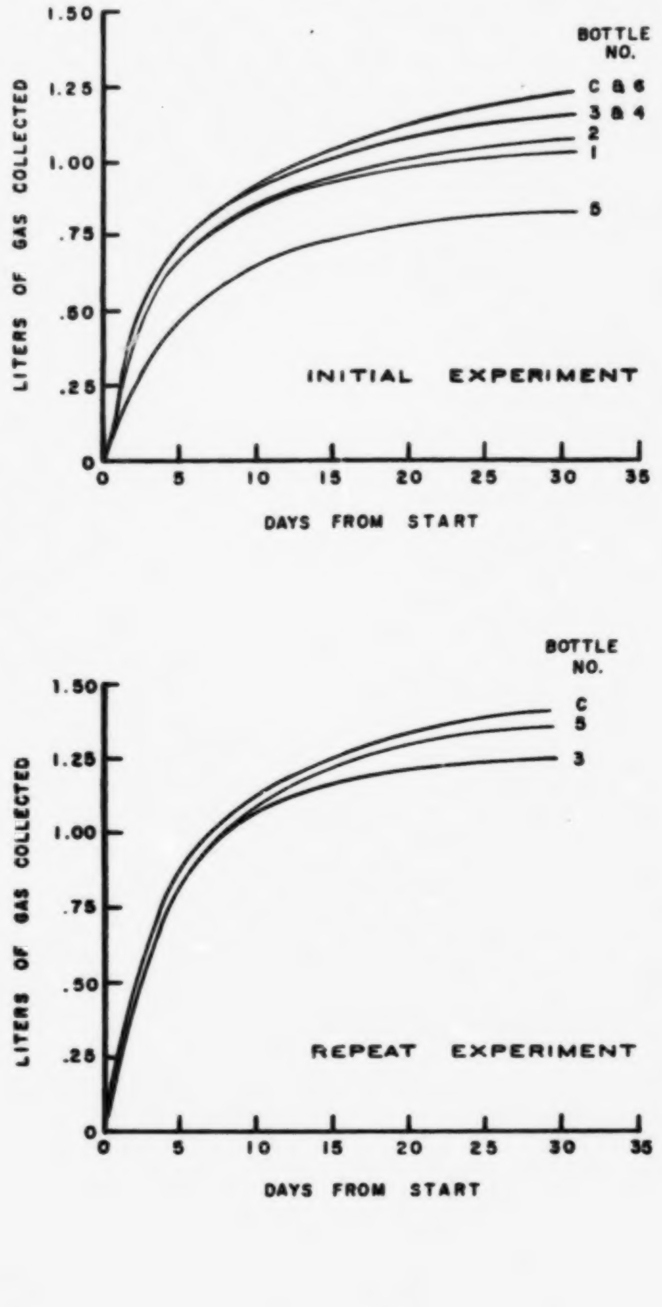


PLATE 37

GAS PRODUCTION — SYNDET
INITIAL CONC. 250 ppm. (WHOLE PROD.)
CONC. DURING COLLECTION 175 ppm.



stable rates were obtained. The particular test dosing treatments were then started and continued until the soils were clogged, or until a stable percolation rate was again reached.

Soap and Syndet Water Treatments—In Average Washday Concentration

DESCRIPTION, PROCEDURES

This study was designed to estimate the relative soil clogging behavior of soap or syndet without the complicating influence of sewage solids. A concentration of 250 p. p. m. (total product) was selected as being about the maximum amount of syndet that might be in a septic tank effluent on a laundry day under average use conditions. For direct comparison, a like concentration of soap was used. Waste kitchen greases from a private home were added to some of the dosing solutions in concentrations of 100 and 200 p. p. m. The make-up of each dosing solution is shown in table 66.

Dosing solutions were prepared once a week. The desired amounts of soap, syndet, and grease were first dissolved in a little hot water, the solutions were then made up to volume, shaken well, and allowed to settle for 24 hours. Supernatant liquor was siphoned off for soil core dosing. Grease content of each dosing solution was determined by extraction with petroleum ether according to Standard Methods (82).

Each solution was dosed to duplicate soil cores of Brookston silty clay previously described, section E, page 68. After clogging, dosing treatments to some of the cores were reversed, those previously receiving soap solution subsequently received syndet solution, and vice versa.

Surface tension values of the dosing solutions and of the percolates from the cores were made occasionally with a DeNoey tensiometer.

RESULTS AND DISCUSSION

Concentrations of grease in each dosing solution are shown in table 66. As the method used measured the grease derived from the soap in addition to the added grease, a correction is made for this factor. On this basis, it is seen that the residual grease is considerably less than the amount added, but that more grease was retained in the supernatant of the syndet solutions than the soap solutions.

The average percolation rates of duplicate cores as they varied with time and with treatment dosings are shown on plate 38. The trends of rates during preliminary tap water dosing are all similar, a gradual decrease to a fairly stable rate about 80 percent of the original. After treatment dosings were started, there was an immediate trend downward in the rates of the soap cores, continuing until a relatively stable value of about 10 percent of original was reached in about 40 days. The rates of the syndet cores also showed a downward trend after an initial lag of about 3 days and continued to reduce until minimum rates of about 35 percent of original were reached on or about the 30th day. The rates then began to increase and continued to do so, until after 40 days the rates were faster than originally.

Among soap solutions, those having the greater amounts of grease caused somewhat greater clogging. The amounts of grease in the syndet solutions seemed to bear no correlation to the ultimate rate values.

Surface tension values shown in table 67 seem to be related to the behavior of the syndet cores. The surface tensions of all of the dosing solutions were depressed, being lower in the syndet solutions than the soap solutions. The surface tensions of the percolates (dosing solutions after they had passed through the soil) of the soap cores rose to about that of tapwater. Evidently, the soap or surface active material was removed or inactivated in the soil. The syndet percolates showed the same trend during the early period of treatment dosing, but after about the 40th day their surface tensions were depressed. This corresponds to about the time when the syndet core percolation rates began to increase. During this time the soap core rates continued to decrease.

TABLE 66.—Relative amounts, in p. p. m., of grease in soap-grease and syndet-grease dosing solutions

Concentration added			Concentration after 24-hour settling	
Soap	Syndet	Grease	Total grease	Due to added grease
250	0	0	104	0
250	0	100	112	8
250	0	200	119	15
0	250	0	2	0
0	250	100	18	16
0	250	200	62	60

PLATE 38

RELATIVE EFFECT OF SOAP AND DETERGENT SOLUTIONS WITH VARYING CONCENTRATIONS OF GREASE ON SOIL CORE PERCOLATION RATES* UNDER CONTINUOUS DOSING

*(Averages of duplicate cores)

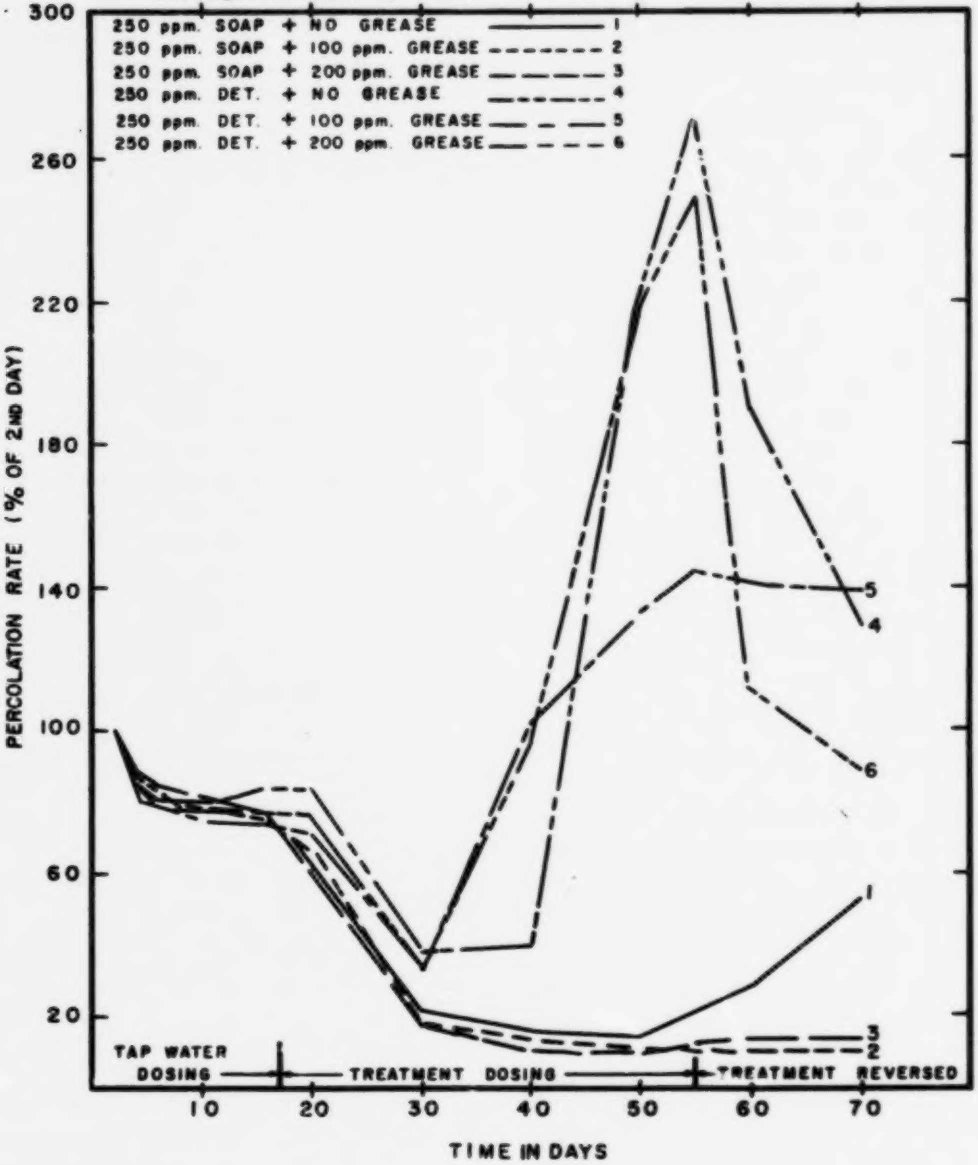


TABLE 67.—Surface tensions of soap and syndet dosing solutions and percolates

	Time from start of experiment	Soap			Syndet		
		No grease	100 p. p. m. grease	200 p. p. m. grease	No grease	100 p. p. m. grease	200 p. p. m. grease
	Days	*Dynes/cm.*	*Dynes/cm.*	*Dynes/cm.*	*Dynes/cm.*	*Dynes/cm.*	*Dynes/cm.*
Dosing solution	21	66.0	64.5	64.0	44.0	45.0	43.0
	22	66.0	64.5	64.0	44.0	45.0	43.0
	42	60.5	57.7	56.0	39.7	39.4	40.5
	50	60.5	57.7	56.0	39.7	39.4	40.5
Percolate	21	72.0	72.3	71.8	73.1	71.4	70.7
	22	71.2	72.2	72.6	73.0	73.0	65.0
	42	72.2	72.3	72.0	53.3	51.8	52.4
	50	71.3	71.6	71.5	50.8	53.0	51.3

At the 55-day point, the syndet treatment of core pairs 4 and 6 was changed to soap, and soap treatment of core pairs 1 and 3 was changed to syndet. Almost immediately, there was a reversal in the rate trends. Core pairs 2 and 5, where treatments were not reversed, continued their previous trends.

Soap and Syndet Water Treatments—In Varying Concentrations

DESCRIPTION, PROCEDURES

This study was designed to investigate the effect of various concentrations of soap and syndet in tapwater solutions on soil clogging. Solutions were made up, as previously described, in concentrations of 50, 100, 200, and 300 p. p. m. (total product). No grease additions were made. The solutions were dosed to cores of Brookston silty clay, the same soil as used in Series 1.

RESULTS AND DISCUSSION

The change in percolation rates with time are shown in table 68. The original percolation rates of these cores were considerably faster than in the previous experiment, and the rates did not change appreciably during preliminary tapwater dosing.

The same general trend in relative clogging by the soap and syndet solutions as shown in Series 1 may be noted in these data. All of the soap cores had lower ultimate rates than the syndet cores. The higher the concentration of soap or syndet, the lower the rate. With the soap cores there was an immediate sharp reduction in rates, and then a gradual leveling off until essentially constant rates were reached. However, the rates of the syndet cores showed an immediate increase and then a decrease, but never to as low values as those of the soap cores. In general, this behavior is similar to that of the cores in Series 1, except that the increase in rates came earlier in the dosing period.

TABLE 68.—Percolation rates[1] of Brookston soil cores dosed with water solutions of soap and syndet in various concentrations

Time (days)	Soap solutions							
	50 p. p. m.		100 p. p. m.		200 p. p. m.		300 p. p. m.	
	Ml./hr.	Percent	Ml./hr.	Percent	Ml./hr.	Percent	Ml./hr.	Percent
2	1, 380	100. 0	1, 310	100. 0	1, 120	100. 0	1, 080	100. 0
4	1, 370	99. 3	1, 300	99. 2	1, 080	96. 4	1, 060	98. 1
6	1, 360	98. 6	1, 290	98. 5	1, 030	92. 0	1, 010	93. 5
8	1, 340	97. 1	1, 270	96. 9	750	67. 0	700	64. 8
10	1, 200	87. 0	1, 230	93. 9	400	35. 7	350	32. 4
15	700	50. 7	650	49. 6	130	11. 6	100	9. 2
20	430	31. 2	210	16. 0	70	6. 2	60	5. 6
30	260	18. 8	100	7. 6	50	4. 5	60	4. 6
40	170	12. 3	70	5. 3	50	4. 5	50	4. 6
50	130	9. 4	60	4. 6	50	4. 5	50	4. 6
60	120	8. 7	60	4. 6	50	4. 5	50	4. 6
70	100	7. 2	60	4. 6	40	3. 6	40	3. 7
80	100	7. 2	60	4. 6	40	3. 6	40	3. 7
90	100	7. 2	60	4. 6	40	3. 6	40	3. 7
100	100	7. 2	70	5. 3	40	3. 6	30	2. 8
110	100	7. 2	60	4. 6	40	3. 6	30	2. 8
120	100	7. 2	50	3. 8	40	3. 6	30	2. 8
Treatment changed	Soap (50 p. p. m.)		Syndet (100 p. p. m.)		Syndet (200 p. p. m.)		Soap (300 p. p. m.)	
130	100	7. 2	1, 700	129. 8	700	62. 5	30	2. 8
140	100	7. 2	2, 400	183. 2	1, 300	116. 1	40	3. 7
150	170	12. 3	1, 600	122. 1	990	88. 4	50	4. 6
160	200	14. 5	1, 500	114. 5	680	60. 7	50	4. 6

Time (days)	Syndet solutions							
	50 p. p. m.		100 p. p. m.		200 p. p. m.		300 p. p. m.	
	Ml./hr.	Percent	Ml./hr.	Percent	Ml./hr.	Percent	Ml./hr.	Percent
2	1, 370	100. 0	1, 200	100. 0	1, 090	100. 0	990	100. 0
4	1, 420	103. 6	1, 220	101. 7	1, 130	103. 7	1, 010	102. 3
6	1, 480	108. 0	1, 260	105. 0	1, 190	109. 2	1, 020	103. 0
8	1, 750	127. 7	1, 400	120. 0	1, 280	117. 4	1, 040	105. 0
10	2, 100	153. 3	2, 300	191. 7	1, 950	178. 9	1, 050	106. 1
15	3, 100	226. 3	2, 700	225. 0	2, 050	188. 1	1, 050	106. 1
20	3, 200	233. 6	2, 250	187. 5	1, 350	123. 8	700	70. 7
30	1, 820	132. 8	1, 460	121. 7	1, 100	100. 9	570	57. 6
40	1, 540	112. 4	1, 070	89. 2	960	88. 1	500	50. 5
50	1, 380	100. 7	930	77. 5	900	82. 6	360	36. 4
60	1, 340	97. 8	820	68. 3	900	82. 6	290	29. 3
70	1, 470	107. 3	770	64. 2	910	83. 5	260	26. 3
80	1, 800	131. 4	740	61. 7	920	84. 4	190	19. 2
90	1, 970	143. 8	730	60. 8	900	82. 6	150	15. 2
100	2, 000	146. 0	720	60. 0	880	80. 7	140	14. 1
110	1, 990	145. 2	720	60. 0	810	74. 3	120	12. 1
120	1, 980	144. 5	720	60. 0	640	58. 7	120	12. 1
Treatment changed	Syndet (50 p. p. m.)		Soap (100 p. p. m.)		Soap (200 p. p. m.)		Syndet (300 p. p. m.)	
130	1, 930	140. 9	140	11. 7	120	11. 0	110	11. 1
140	1, 820	132. 8	70	5. 8	60	55. 5	110	11. 1
150	1, 400	102. 2	50	4. 2	50	4. 6	100	10. 1
160	1, 000	73. 0	50	4. 2	50	4. 6	100	10. 1

---

[1] Percent rate is based on the rates at the start of treatment dosing being 100 percent, which were the same as the original rates.

The surface tensions and pH's of the dosing solutions and percolates were determined about every other day. There was considerable variation from day to day, so that in order to obtain trend values, the data were plotted against time and a trend line fitted by eye. The trend values are summarized in table 69.

TABLE 69.—Surface tension and pH values of dosing solutions and percolates from soil cores dosed with soap and syndet

	Soap (p. p. m.)								Syndet (p. p. m.)							
	50		100		200		300		50		100		200		300	
	S. T.[1]	pH	S. T.	pH	S. T.	pH	S. T.	pH	S. T.	pH	S. T.	pH	S. T.	pH	S. T.	pH
Dosing solution	58	6.9	56.0	6.9	54.0	6.9	53.0	6.9	53	6.9	49	6.9	42	6.9	41	6.9
Percolate	71	8.0	71.5	8.4	71.5	8.4	71.5	8.4	59	7.5	54	7.6	48	7.5	48	7.6

[1] S. T.—Surface tension in dynes/cm.

It may be noted that the syndet solutions had lower surface tensions than the soap solutions, and in both cases the higher the concentrations, the lower the surface tension. The surface tensions of the percolates were all higher than the dosing solutions, indicating that surface active material was removed or inactivated in the flow through the soil. However, the syndet percolate still maintained some depression of surface tension, again indicating some relationship between surface tension and higher percolation rates.

The pH values of percolates were higher than comparable dosing solutions, the pH of the soap percolate being higher than that of syndet percolate.

After 120 days of dosing, treatments to four cores were changed, as indicated in table 68. There was an immediate tendency for cores now dosed with syndet to increase in rate, and with soap, to decrease.

Soap and Syndet Home Laundry Water Treatments

DESCRIPTION, PROCEDURES

The washwater from the laundering for three adults was collected each week for dosing to soil cores. A soap and a syndet, of the same brand used in the previous experiment, were used on alternate weeks. The washwaters were refrigerated until used. Effluent collected daily from one of the experimental septic tanks was used as a control. The washwaters and effluent were dosed to soil cores, daily percolation rates determined, etc., according to procedures previously described. At the conclusion of the experiment, cores were dismantled and aggregate stability determinations were made.

Soils.—Four soil types representing a wide variety of soils were used; some of their physical characteristics are shown in table 70. The Brookston and Clermont soils were both poorly drained and had slow percolation rates in place. The Fox clay loam was somewhat better drained, but had a very unstable structure. The Fox sandy loam had a very fast percolation rate. It had a single-grain structure, but on being dried and prepared for cores it formed into small hard aggregates which were very stable to wetting.

TABLE 70.—Soils used in laundry water experiment

Soil name	Texture				Structure	
	Classification	Sand	Silt	Clay	Classification	Water stability
		Percent	*Percent*	*Percent*		*Percent*
Fox	Sandy loam	62	19	19	Single-grain	61
Brookston	Silty clay loam	13	53	34	Blocky	50
Fox	Clay loam	27	33	40	Fragmental	12
Clermont	Silty clay	17	42	41	Flatey	62

RESULTS AND DISCUSSION

The average solids content of the dosing solutions are shown in table 71. The concentrations of solids in the laundry waters are considerably higher than in the septic tank effluent.

TABLE 71.—Average solids content of dosing solutions

Item (p. p. m.)	Effluent	Laundry water	
		Soap	Syndet
Total solids	794	4,835	5,806
Ash	500	1,864	2,973
Volatile	294	2,971	2,833
Suspended solids	188	1,702	2,764
Ash	58	160	1,044
Volatile	130	1,542	1,720
Dissolved solids	606	3,133	3,042
Ash	442	1,704	1,929
Volatile	164	1,429	1,113

For direct comparison of treatment effects, the average rates of duplicate cores, expressed as percent of original, are summarized in table 72.

At the end of treatment dosing, when cores had been dosed for equal lengths of time, and also at the point where equal volumes of liquid had been passed by the cores, both the soap and syndet laundry waters had caused greater clogging than the effluent. There appears to be no difference in clogging between soap and syndet. With two of the soils, the soap cores show slightly lower rates; while with the other two, syndet cores are slightly lower. Considering variation among duplicates, the differences are not significant.

When compared at the point where equal amounts of suspended solids had been added, there again is no significant difference in clogging between soap and syndet laundry waters. However, comparing laundry waters against effluents, variable results are evident. In Brookston soil, the laundry waters cause less clogging; in the two Fox soils, laundry waters and effluent cause about the same clogging; in Clermont, the laundry waters cause a great deal more clogging than effluent.

TABLE 72.—Comparative percolation rates [1] of soil cores dosed with septic tank effluent and with soap and syndet laundry waters

	Dosing solution		
	Effluent	Laundry water	
		Soap	Syndet
Rates at end of treatment dosing			
Brookston silty clay loam	3.3	1.4	0.7
Fox sandy loam	4.3	.8	.3
Fox clay loam	4.5	1.1	1.2
Clermont silty clay	3.2	.3	.4
Rates after cumulative addition of 6 gm. of solids			
Brookston silty clay loam	3.4	14.1	13.0
Fox sandy loam	4.3	5.5	5.6
Fox clay loam	7.9	10.0	9.4
Clermont silty clay	302.6	5.0	9.4
Rates after adding equal volumes of dosing solution			
Brookston silty clay loam	21.5	1.9	0.7
Fox sandy loam	13.2	.8	.4
Fox clay loam	21.3	3.9	1.2
Clermont silty clay	288.0	.3	.5

[1] Rate values are given as percent of original rate, and each value is the average of 2 cores.

The aggregate stabilities of the soils after dosing treatments were completed are shown in table 73. It will be noted that, for three of the soils, the average aggregate stability of the laundry water dosed cores is lower than that of the effluent dosed cores. In that aggregate stability is an index of sustained permeability, this confirms the trends of the percolation rates that raw laundry waters in general caused greater clogging than septic tank effluent.

Concerning soap versus syndet, it will be noted that in all cases the syndet dosed soils have slightly lower aggregate stabilities. This would indicate that, even though it was not reflected in the short-time percolation rate trends, syndets in raw laundry waters may be slightly more damaging than soap from a long-time viewpoint.

Soap and Syndet Effluent Treatments

INTRODUCTION

In order to investigate the relative effect of soap and syndet on soil clogging when all normal clogging factors are considered, soil cores were dosed with septic tank effluents having added amounts of soap and syndet. Effluent without any additions was used as a control. The same types of soap and syndet as used previously were used in this experiment.

DESCRIPTION, PROCEDURES

Dosing Solutions.—Effluent from one of the experimental septic tanks was collected daily and divided into three volumes. To one volume, 250 p. p. m. of soap powder was added; to a second volume 250 p. p. m. syndet product was added; and the third volume was used as a control. Some coagulation took place when the soap or syndet powders were added, so the solutions were allowed to settle and the supernatant used for dosing.

Soils.—Two soils were used for the experiment, Brookston silty clay loam and Miami clay loam, both of which are fully described in section E. The cores were packed and pre-dosed with tapwater in the usual manner, and then dosed with the effluent solutions for about 2 months. All treatments were applied to duplicate cores.

TABLE 73.—Aggregate stability [1] of soils dosed with effluent and with soap and syndet laundry water

Original soil (percent)	Treated soils		
	Effluent (percent)	Laundry water	
		Soap (percent)	Syndet (percent)
	Brookston silty clay loam		
51	34	26	28
49	34	32	21
	36	32	28
	36	40	27
Average 50	35	32.5	26
	Fox sandy loam		
63	49	46	38
59	35	39	36
	60	43	36
	52	41	34
Average 61	49	42.8	36
	Fox clay loam		
11	9	9	6
14	8	7	6
	7	9	7
	7	8	6
Average 12.5	7.8	8.2	6.2
	Clermont silty clay		
60	64	39	15
64	62	43	15
	65	42	15
	63	40	15
Average 62	63.5	41	15

[1] Determined by the Bryant Short Method, as described in sec. E. Reported as percent of soil retained on a 35-mesh sieve after washing in water for 5 minutes.

RESULTS AND DISCUSSION

Percolation rates at critical points in the dosing period are given in table 74. The trend of the percolation rates during the tapwater dosing followed the usual pattern, the rates reducing to about 80 percent of the original.

The usual pattern of progressive clogging during the treatment dosing also took place. The rates of all of the cores came to rather stable values after 70 days of dosing. At the end of treatment, dosing the effluents with added soap and syndet had caused greater clogging than the normal effluent. There was no apparent difference in the clogging between the soap and syndet effluents; i. e., with the Brookston cores, the average rates were 12.7 and 10.9 percent of the originals for soap and syndet effluents, respectively, while with the Miami cores the rates were 20.6 and 20.8 percent, respectively.

At the point where 1.4 grams of solids had been added to all of the cores, there was no difference in the clogging between normal effluent and effluent plus soap, but possibly slightly more clogging by the effluent plus syndet treatment as judged by the average rates. Considering the variability between individual cores under duplicate treatment, however, there is probably no significant difference in the clogging caused by any of the three solutions.

Field Soil Study

A field study of the relative clogging effects of soap and syndet solutions was incorporated into the auger hole study described and discussed in section E.

DESCRIPTION, PROCEDURES

When the above mentioned auger hole study of clogging characteristics of effluents was finished, 250 p. p. m. concentration tapwater solutions of soap and of syndet were dosed to the holes to note

TABLE 74.—Percolation rates of soil cores dosed with septic tank effluent with and without soap and syndet additions

Brookston silty clay loam

Point in dosing period	Normal effluent				Effluent+soap				Effluent+syndet			
	Number 1 Ml./hr.	Number 2 Ml./hr.	Average		Number 1 Ml./hr.	Number 2 Ml./hr.	Average		Number 1 Ml./hr.	Number 2 Ml./hr.	Average	
			Ml./hr.	Percent			Ml./hr.	Percent			Ml./hr.	Percent
Start of water dosing	165.0	143.0	154.0	100.0	195.0	120.0	157.5	100.0	190.0	130.0	160.0	100.0
Start of treatment dosing	133.0	110.0	121.5	78.9	152.0	110.0	131.0	83.2	150.0	110.0	130.0	81.2
End of treatment dosing	25.0	25.0	25.0	16.2	20.0	20.0	20.0	12.7	18.0	17.0	17.5	10.9
After accumulation of 1.4 gm. suspended solids	26.0	26.0	26.0	16.9	30.0	29.0	29.5	18.7	27.0	18.0	23.0	14.4
	Miami clay loam											
Start of water dosing	25.0	25.0	25.0	100.0	21.4	20.8	21.1	100.0	20.7	19.6	20.2	100.0
Start of treatment dosing	20.0	19.1	19.5	78.0	16.7	16.7	16.7	78.0	16.4	16.9	16.6	82.2
End of treatment dosing	7.8	5.1	6.4	25.6	4.7	4.2	4.4	20.6	3.8	4.5	4.2	20.8
After accumulation of 1.1 gm. suspended solids	8.4	5.0	6.7	26.8	5.5	5.4	5.4	25.2	3.7	5.2	4.4	21.8

any further effect on percolation. The holes were dosed for about three weeks, during which time the rates approached equilibrium values. The soap and syndet used were the same as those used in the laboratory soil studies.

RESULTS AND DISCUSSION

The rates for individual holes, taken from a smooth curve drawn through the original data, are given in table 75. It is evident that there is a difference in soil clogging between the tapwater solutions of soap and of syndet. In every instance, the holes receiving the soap solutions have the lower percolation rates, those of the soap dosed holes averaging 0.64 inch per hour, and those of the syndet dosed holes, 1.05 inches per hour. The average rates of the same holes prior to being dosed with soap and syndet solutions were 1.23 and 1.31 inches per hour, respectively.

In 4 of the 6 holes dosed with soap solution, the final percolation rates were lower than the rates prior to the soap treatment, while in the syndet dosed holes, the final rates were higher in 5 out of 6 cases. These results are in agreement with the laboratory results of core clogging by tapwater solutions. It must be remembered that the complicating clogging influence of solid particles is not included in this study. Were this factor included, we might expect similar results as obtained in the laboratory; that is, the clogging is more influenced by solids content than by the soap or syndet itself.

A soil examination made following completion of the study (see table 53, sec. E) showed no consistent difference in aggregate stability, possibly because of confounding caused by prior treatment, between soap and syndet.

TABLE 75.—Percolation rates in auger holes dosed with soap and syndet water solutions [1]

Hole No.	Percolation rate (inches per hour)			
	Prior to treatment		20 days after treatment	
	Soap	Syndet	Soap	Syndet
1	1.30		0.35	
2		1.35		1.10
3	1.10		.30	
4		1.25		1.00
5	1.10		.45	
6		1.15		1.00
7	1.05		.45	
8		1.30		1.00
9	1.50		1.05	
10		1.45		1.15
11	1.30		55	
12		1.35		1.05
Average	1.23	1.31	.64	1.05

[1] See Table 51, sec. F, for previous study in same auger holes.

SECTION I

Evapotranspiration and Plant Growth in Relationship to Soil Absorption System Operation

INTRODUCTION

It is common knowledge that many soil absorption systems operate more satisfactorily in summer months than in winter months. Several systems have been observed in the Cincinnati area during the course of the studies which, because of impermeable or clogged soils, would not have been expected to operate successfully; yet they gave satisfactory performance during most of the year. Further observation of the systems suggested that their success might be attributed to evaporation, transpiration, and root permeation of the soil. A heavy growth of vegetation existed over most of the areas, being particularly dense and luxuriant directly over the disposal trenches. The soil was well permeated with roots, and there were heavy concentrations of roots in the gravel fill of the trench. The observations further suggested that consideration of the plant-growth factors in the specific design of systems might be advantageous. A review of the literature to explore the subject has been made.

Evapotranspiration—Actual

INFLUENCING FACTORS

Soil acts as a reservoir from which water is withdrawn by evaporation from the soil surface and by transpiration from growing plants. The two processes are influenced, to a large extent, by the same factors. It is difficult to measure moisture withdrawal by each process separately. Consequently, for practical purposes, they are generally considered as one process, evapotranspiration. Values of moisture withdrawal by these means are commonly given in acre-inches per acre, or simply as inches, or feet, of depth over the area considered per unit of time. In considering large areas, the term "consumptive use" is used synonomously with evapotranspiration.

The rate of evapotranspiration depends primarily on three factors, namely, the nature of the vegetation, soil conditions, and climate.

Vegetation.—The nature of vegetation affects the rate of evapotranspiration primarily through its effect on transpiration alone.

Transpiration varies widely for different types of plants, and may also vary for different varieties of the same type. The use of water by plants depends to a large extent upon the extent of their root systems and the length of growing season for the particular plant. In general, the alfalfas and clovers are among the heaviest water users. Blaney and Criddle (83) present data indicating that for the western United States alfalfa uses from 22 to 52 inches of moisture annually, depending to some extent on the amount available and the length of growing season. Use by pasture grasses ranges from 19 to 25 inches, orchard trees, from 20 to 40 inches annually. Values for western native plants, such as tule and cattail, range up to 16 feet annually. In eastern United States, these values would be less; for instance, Meyer (84) gives tentative base values of 9 to 10 inches annually for grasses, 6 to 8 inches for small trees and brush, 8 to 12 inches for deciduous trees, and 4 to 6 inches for coniferous trees, in the north central part of the United States.

Density and stage of growth, and depth and extent of root system, also influence soil water loss. Dense plant covers decrease the amount of water lost by direct evaporation, but this is more than offset by the increased loss through transpiration. On the whole, transpiration by deep-rooted plants tends to be greater and to fluctuate less with varying conditions of moisture, than that by shallow-rooted plants.

Transpiration is roughly proportional to leaf area and to the amount of dry material produced in growth.

No estimate can be made as to how much evapotranspiration may be increased by modifying plant cover, but all indications point to a possibility of being able to maintain a maximum by proper selection of plants and proper land management.

Soil.—The quantity of moisture used by a particular plant depends mainly on the quantity available to the plant. In any given soil, there is a moisture content at which all plants wilt and transpiration ceases. This value varies tremendously for different soils. As the moisture content is increased, both transpiration and evaporation increase up to a maximum at about the field moisture holding capacity (or the moisture content to which a soil drains in 24 to 48 hours after being saturated). Above this point, there is no increase in water loss, and there may be a decrease with plants that are susceptible to waterlogging.

Texture, structure, and depth of soil further influence transpiration values. In heavy clay soils, plants obtain water only in the upper layers, while in sandy soils or deep loamy soils water is obtained over greater depths because of the easier penetrability by roots.

The depth to ground water also influences soil water loss. Evaporation from ground water takes place where the water table is high enough that capillarity can raise water to maintain a moisture supply at the surface. From a review of investigations, Houk (24) concludes that rates of soil evaporation decrease rapidly with increasing depths to a water table, particularly in the first two feet of depth; and that in most soils, rates of evaporation from ground water supplies become negligible when the water table falls to a depth of more than about four feet. Transpiration likewise tends to decrease with increasing depths to water because of the decrease in moisture available to the plant. Evapotranspiration is of most value in aiding the operation of a tile field where the water table is at least four feet deep; in such case, moisture for plant use and evaporation is supplied from effluent and not from ground water.

By providing or selecting proper soil conditions, it appears that the maximum value of evapotranspiration to soil absorption systems might be developed.

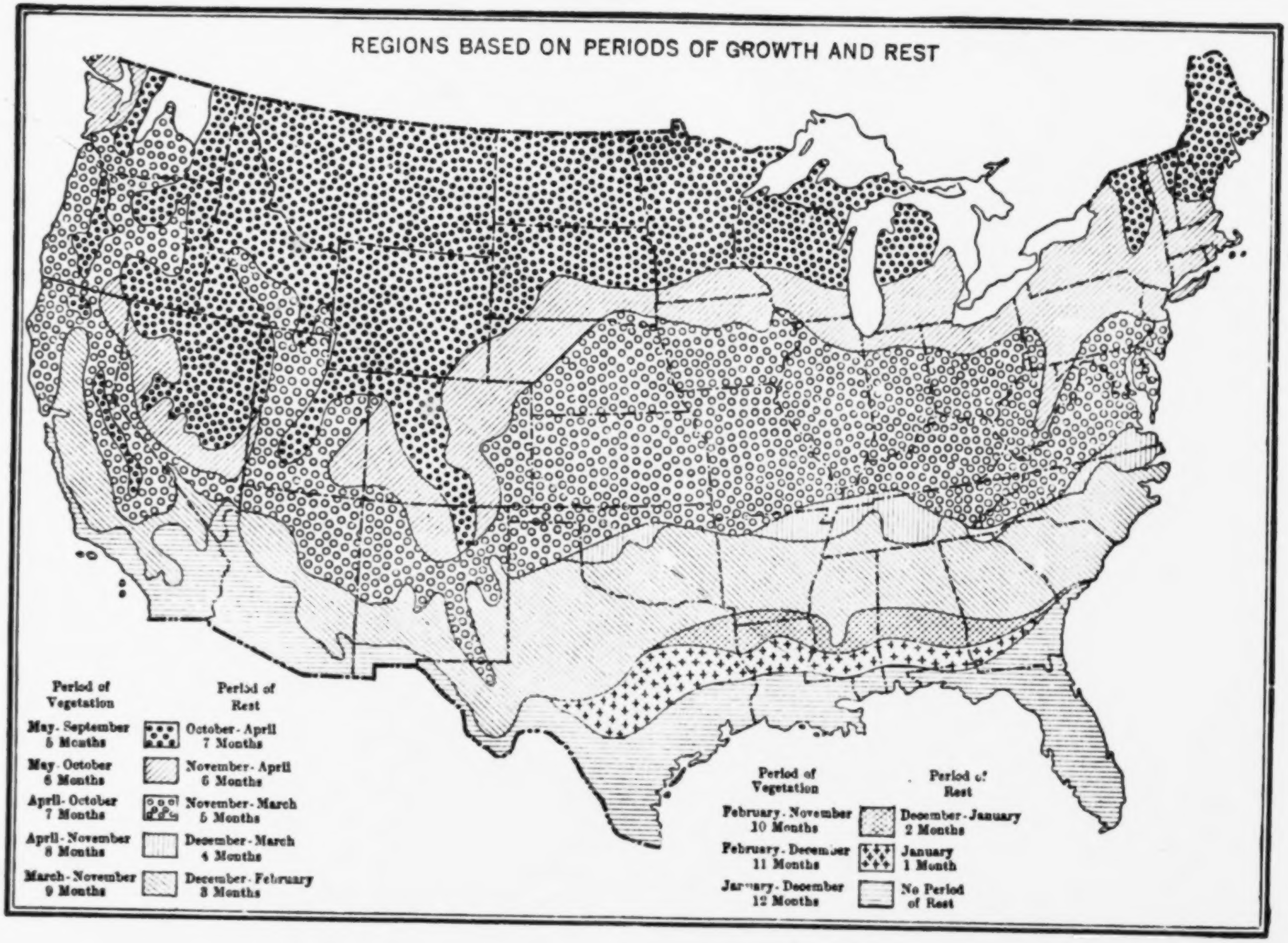
Climate.—Probably the most important single factor influencing the amount of water removed from soil by evapotranspiration, and one which cannot be controlled, is climate. Weather conditions that control evaporation, primarily temperature, humidity, and wind movement, also affect transpiration. Changes in evapotranspiration accompany diurnal and seasonal changes in weather conditions. Evapotranspiration increases with decreasing humidity and increasing temperature and air turbulence. Length of day and amount of sunshine are further influencing factors.

Climate is important also through its control of plant-growing seasons. Regions of the United States based on periods of growth and rest (84) are shown on plate 39. It may be noted that the growing season in the extreme southern portion of the country extends over the full year. Evapotranspiration should be of most benefit to soil absorption systems in this region. In the extreme North, the growing season extends only from May to September. From the overall viewpoint, evapotranspiration would be of minimum value in this region.

Evapotranspiration—Potential

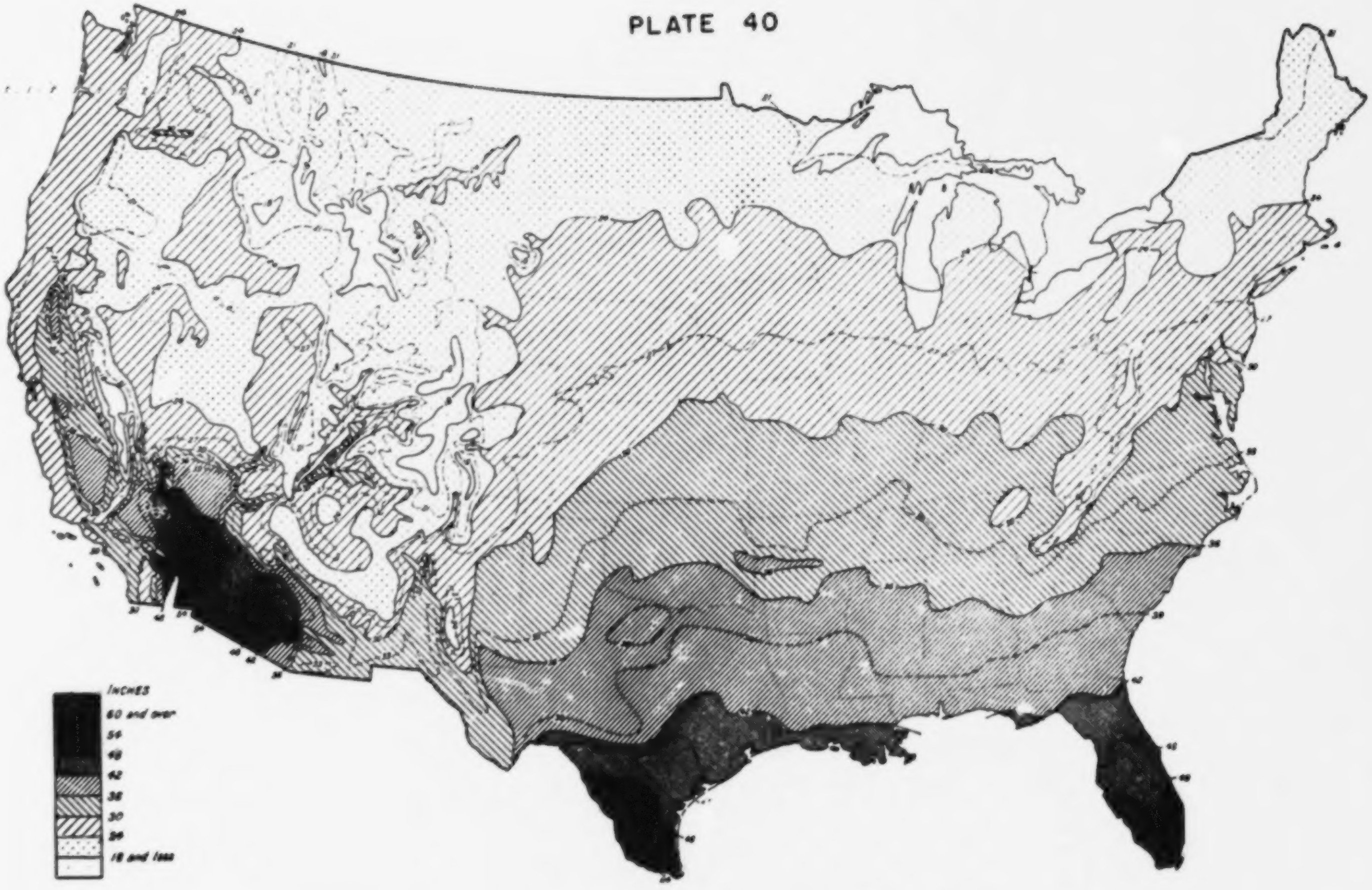
Measurements of actual evapotranspiration are rather meager. Furthermore, they were made under soil and plant conditions prevailing at a particular time. More of interest in judging the value of evapotranspiration to soil absorption systems operation would be the potential amounts of water, based on a long-time average, that would be used under optimum soil and plant conditions, such as might be established in a soil absorption system. Thornthwaite (85) makes a distinction between actual and potential evapotranspiration, defining the latter as the amount of water that would transpire and evaporate if it were available, a maximum that depends only on climate. With this definition in mind, he has developed an empirical formula that permits an estimation of potential evapotranspiration, having latitude and temperature records. Plate 40 shows the distribution of average annual potential evapotranspiration in the United States, based on this formula.

PLATE 39


REGIONS BASED ON PERIODS OF GROWTH AND REST
Period of Vegetation
Period of Rest
May - September 5 Months
October - April 7 Months
May - October 6 Months
November - April 6 Months
April - October 7 Months
November - March 5 Months
April - November 8 Months
December - March 4 Months
March - November 9 Months
December - February 3 Months
Period of Vegetation
Period of Rest
February - November 10 Months
December - January 2 Months
February - December 11 Months
January 1 Month
January - December 12 Months
No Period of Rest

Vegetal Regions in the United States Based on Periods of Growth and Rest [after Zon (91)]

PLATE 40


INCHES
60 and over
54
48
42
36
30
24
18 and less

Average annual potential evapotranspiration in the United States. [After Thornthwaite (85)]
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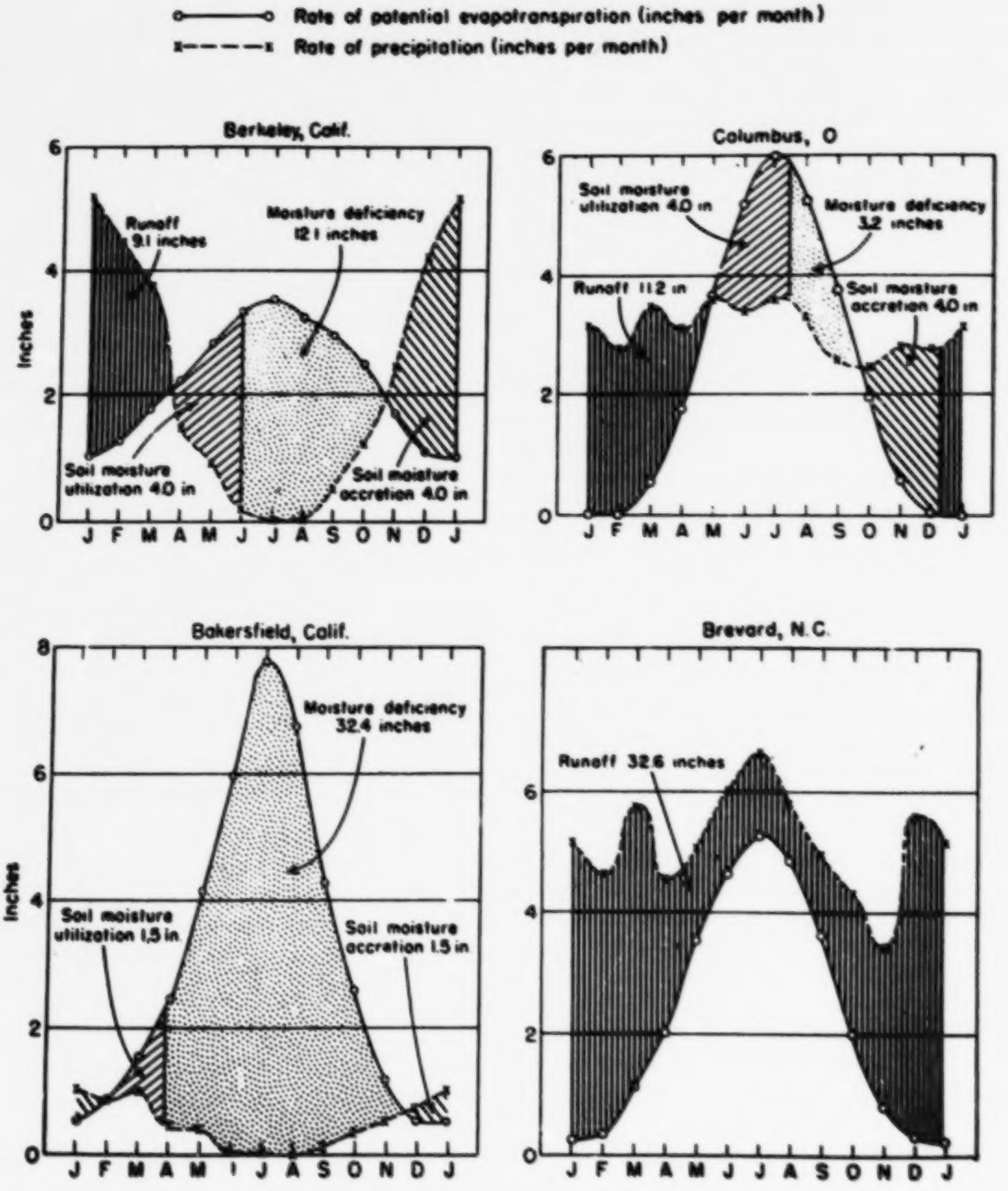
PLATE 41



Relation between precipitation and potential evapotranspiration at selected stations.
[after Thornthwaite (85)]
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The potentials range from less than 18 inches annually in the mountains of the West, to more than 60 inches in the deserts of Arizona and California. In the area east of the Rocky Mountains, they range from about 20 inches in the North to about 50 inches annually in the South.

Blaney and Criddle (83), among others, have developed formulae for estimating irrigation water requirements, which are also estimates of potential evapotranspiration, and which depend on a minimum of climatological data. Temperature, length of growing season, and daytime hours are related empirically to "consumptive use" of specific crops. Blaney and Criddle (83) data indicate that alfalfa, clover, and pasture grasses are among the heaviest water users.

The monthly variation in potential evapotranspiration through the year follows a uniform pattern in most of the country, being a minimum, and in many areas, negligible, in the winter months, and rising to a maximum in July. The magnitude of the monthly values varies considerably for different areas, as indicated on plate 41. Values for Bakersfield and Berkeley, Calif., are significantly large for each month, ranging from about 1 inch in winter to almost 8 inches in summer. Values for Columbus, Ohio, are negligible in the 3 winter months, and rise to about 6 inches in July.

Evapotranspiration Versus Rainfall

The amount of water removed from a soil by evapotranspiration, in order to be beneficial to soil absorption system operation, obviously should exceed the amount added by precipitation. The difference would be the potential amount of effluent that might be removed. As interpreted from Wrather (87), roughly one-third of rainfall finds its way back to streams through surface and underground runoff, leaving approximately two-thirds of rainfall available for evapotranspiration. Thus, in the United States, the amount of rainfall available for evapotranspiration ranges from less than 5 up to about 66 inches annually, and potential annual evapotranspiration exceeds rainfall available for evapotranspiration by from around 50 inches in the southwest to less than 5 inches in the Northeast.

The pattern of precipitation over the year almost never coincides with changing demands for soil water. Thus, a better comparison of evapotranspiration and rainfall may be made on a monthly basis, such as shown on plate 41. On this plate, the extent to which rainfall satisfies evapotranspiration and, therefore, the extent to which evapotranspiration might utilize effluent from a soil absorption field, is indicated. In the runoff period, when the soil is saturated and rainfall exceeds evapotranspiration, little benefit to soil absorption system operation could be expected. In the soil moisture utilization period, wherein evapotranspiration exceeds rainfall and plant growth must depend on stored soil water, effluent could be utilized. In the moisture deficiency period, there is a critical need for additional moisture in order to maintain potential evapotranspiration. Absorption field operation should benefit most during this period. In the soil moisture accretion period, rainfall again exceeds evapotranspiration, but some effluent might be used in satisfying soil moisture storage.

It may also be noted from plate 41 that the value of evapotranspiration to soil absorption systems varies from place to place. At Brevard, N. C., there is a moisture surplus during every month, so that we would expect little evapotranspiration benefit. At the other extreme, at Bakersfield, Calif., there is a long period of moisture deficiency when we might expect maximum benefit. However, it is obvious that in most areas there is at least a month or more when little or no benefit would accrue.

Root Growth

Plant growth may be of benefit to soil absorption systems other than through evapotranspiration influence. A soil permeated with roots tends to have improved absorption capacity. There is a growing belief, according to Baver (19), that plant roots are as important as any other factor in the production of stable soil granulation, which favors improved permeability. Penetration of roots into the soil opens channels which, after the roots die and decay, remain for long periods of time, greatly increasing the pore space and absorption of water. Such channels may be readily traced many feet into the soil and subsoil.

A good vegetation cover also promotes an abundant and active soil fauna which in turn improves permeability. Soil is permeated with channels of earthworms, beetles, etc., which make it more rapidly permeable to water.

Growth of roots into distribution tile of a soil absorption system is considered by some a cause of system failure. Limited observations of root behavior in soil absorption fields tend to disprove this. In one system, discussed previously (2), a dense accumulation of roots was found in the gravel fill below the tile distributor and in the soil surrounding the trench, while practically no roots were in the tile.

In a survey of soil absorption systems in Duval County, Fla., relative to effect of garbage-grinders, some 98 trench sections were examined. In 83 of the 98 cases, there were no roots in the tile proper, in 12 cases there were "few" roots, and in only 3 cases were the roots in the tile classed as "many." In no case was there any evidence of flow stoppage due to roots.

In 89 of the 98 cases, there were "few" to "many" roots in the trench filler material below the tile. Apparently, the roots seek the location where moisture conditions are most favorable for growth, particularly grass roots. Tree roots seemed to follow a random pattern of growth, and in one case had grown between 2 tile sections, disturbing the alignment.

An investigation of 482 septic tank systems in 1 county in Florida (88) showed that 11 of the systems had been clogged due to roots, and 23 clogged due to deficiencies in maintenance and operation.

SECTION J

Supplemental Investigations

Distribution Appurtenances

INTRODUCTION

For the most efficient operation of soil absorption systems, it is generally considered that the volume of effluent disposal to separate parts of a system should be distributed equally over the system. On sloping lots unequal distribution risks surface seepage from the overloaded parts of the system. Various devices including distribution boxes, tees, wyes ("herringbone" layouts), and other divider arrangements have been offered for this purpose. Little information appears to be available concerning comparative efficiencies.

In connection with distribution devices, it might be mentioned here that dosing chambers with automatic siphons are not generally recommended for residential systems by the various control agencies in the United States.

DISTRIBUTION BOX

A report (92) of tests on one distribution box by an engineering firm was reviewed. The box was hexagon-shaped, approximately 12 inches in diameter, with a 3.75-inch hole in each side. The sides were 8 inches long and 6½ inches deep. Inlet and outlet holes were on the same level, with inverts approximately 2 inches from the floor. A baffle projected from the inlet, with its lower edge level with the inverts.

Hydraulic characteristics of the distributing box were studied through a series of flow tests using clear water. Water was discharged into the box at a measured rate, and the flow from each outlet was collected and weighed. Actual flow deviations from theoretical for each outlet were averaged for use in determining efficiency. Efficiency was approximately 98.5 percent at flows ranging from 3 and 11 g. p. m., 99 at 55.5 g. p. m., and 85 at 0.1 g. p. m. With the two outlets to the left of the inlet closed, efficiency of the remaining three was approximately 97 percent at 11 g. p. m.

A discussion with the engineers in charge of the tests revealed that initial tests were made without benefit of an inlet baffle, and poor distribution was observed. With the addition of a baffle, experimentally placed, improved distribution characteristics reported were obtained.

TEE AS DIVIDER

Effluent from a 500-gallon laboratory septic tank was conducted through a 2-foot length of pipe to a tee, where the flow was divided and carried to collecting drums. Two hundred and fifty gallons of raw sewage were fed to the tank in 8 daily feeds, following the established procedure for these experiments. All pipe and fittings were 4-inch bell and spigot vitrified clay pipe, ordered, without preselection, from a building supply firm.

The pipe leading from the tank to the tee was given a fall of one-eighth of an inch per foot, and each of the 2-foot long discharge pipes between tee and drum was set level. Care was taken in grouting sections together to insure smooth joints.

Over a period of approximately 10 days, 2,540 gallons of effluent were passed through the tee. One drum received 2,150 gallons, or approximately 85 percent of the discharge. Similarly poor results were obtained when the tee was reversed.

WYE AS DIVIDER

Effluent from a 500-gallon laboratory septic tank was discharged to a short tile line consisting of 2 straight 2-foot sections, a wye, a straight section, and finally another wye with its branch on the opposite side of the trunk line. Collecting drums were placed to catch the discharge from each of the Y-branches, and from the end of the trunk line. All pipe and fittings were four-inch bell and spigot vitrified clay pipe, ordered, without preselection, from a building supply firm.

Care was taken in grouting sections together to insure smooth joints.

Trial at Two Percent Slope.—The first trial was made with the distribution line set at a 2-percent slope. Two hundred and fifty gallons of sewage were fed to the tank in 8 daily feeds, following the established procedure for these experiments. After approximately 16 days, 3,952 gallons of effluent had passed through this line. The first wye branch diverted 268 gallons, the second 286 gallons, and the remainder, 3,398 gallons (about 86 percent of total flow), was discharged at the end of the line.

At this relatively steep slope, there was essentially equal lateral distribution by the 2 wyes. However, the large quantity of effluent passing beyond the 2 wye take-offs indicate that a large number of diversions and a long length of main distributor might ultimately be required for complete distribution. Furthermore, considering the two percent slope, the long main distributors would involve increased trench depths.

Trial at 0.5-Percent Slope.—A second trial was conducted over a longer period with the distribution line set at a 0.5 percent slope. A total of 7,824 gallons of effluent passed through the line. The first wye branch diverted 3,612 gallons, the second 965 gallons, and the remainder, 3,247 gallons, was discharged at the end of the line. Thus, it is evident that at one-half percent slope the diversion at 1 wye was almost 4 times that of the other. A large portion of the effluent, 42 percent, flowed by both branches.

Sludge and Scum Measuring Devices

Because of extreme variation in rate of solids accumulations among individual cases, as evidenced in section C, page 41, it appears that periodic measurement of sludge and scum accumulations is important in determining when a tank must be cleaned. Cleaning time develops when either the top of sludge or the bottom of scum approaches minimum distances (minimum clear spaces) from the bottom of the outlet tee or baffle. Minimum clear spaces for 500-gallon, straight vertical-side tanks are discussed in section B.

Sketches of a sludge-sighting tube and a scum-measuring device developed for use in these studies are shown in a previous report (1). Investigations were also made on simple and inexpensive devices for use by homeowners. For sludge measurements, best results were obtained with a strip of turkish toweling tacked to a stick. The stick was lowered to the bottom of a tank and allowed to remain for several minutes. After it was removed, the sludge line could be distinguished by sludge particles clinging to the towel. Measurements thus obtained, both in the laboratory and in the field, were within one-half an inch of those obtained with the sludge-sighting tube.

Design Improvements to Facilitate Cleaning

Recent experience in the field indicates that consideration should be given to providing more accessible tank openings for inspection and servicing operations. A feature proving useful is an inspection hole over the tank outlet, with extension, if necessary, to within about 6 inches of the ground surface. The hole provides easy access to measure scum and sludge accumulations.

Also proving useful is a servicing manhole over the inlet, in lieu of removable tops or slabs, to provide access for tank cleaning and servicing of stoppages. Such access manholes may also be extended to within 6 inches of ground surface for convenience in opening.

Chemical Septic Tank "Cleaning" Products

INTRODUCTION

According to their labels, some of the proprietary products purported to "clean" septic tanks contain sodium hydroxide as the active agent. One such product, on chemical analysis, was found to contain the equivalent of 97 percent sodium hydroxide, when calculated as sodium hydroxide. Some "cleaners" are indicated as being primarily potassium hydroxide. In view of numerous inquiries concerning the value of such products in the household sewage disposal system, a limited study, using the active agents above mentioned, was undertaken.

MODEL TANK STUDY

Procedure.—Sludge and supernatant liquid were drawn from an experimental septic tank and placed in a glass-sided tank whose approximate dimensions were 11″ x 19″ x 12″ deep. This mixture was allowed to stand at room temperature for three days. At the end of the 3-day period, the sludge had settled to the bottom of the tank and formed a well-defined layer 2 inches deep. The supernatant liquid was relatively clear, with a few large and many fine particles in suspension. The total depth of liquid and sludge in the tank was 7½ inches. A strong solution of sodium hydroxide was poured slowly into one end of the tank.

Results and Discussion.—The solution flowed down the side of the tank and under the sludge, floating it about 3 inches above its original level. Fifteen minutes later, particles started breaking away from the sludge blanket and settling to the bottom of the tank. A mound appeared in the center of the sludge, becoming larger until a tank "turnover" resulted.

The supernatant liquid became dark. A small amount of gas was evolved, but not enough to explain the turnover. There were no large bubbles of gas evolved when the sludge mound broke. After the tank "turnover," the dividing line between sludge and supernatant became rather indistinct. The sludge increased in volume with its new level about 4½ inches above the bottom of the tank. Before the sodium hydroxide was added, the sludge had a distinct granular structure. Afterwards, it became a viscous, homogeneous mass having the consistency and appearance of a heavy, used motor oil. Sludge flowed easily into a battery syringe when a sample was withdrawn to determine its pH, found to be 12.9. A slight scum, not thick enough to measure, appeared after the tank "turnover." There was no noticeable odor during the experiment.

FULL-SCALE TANK STUDY

Procedure.—In a similar experiment, 25 pounds of commercial-grade sodium hydroxide was added to a full-size experimental septic tank which had been in normal operation for approximately a year. The tank, which had a liquid capacity of 455 gallons, has been referred to as tank No. 6 in previous reports (1, 2). Sewage dosings, and determinations of solids, pH's, etc., were made as previously described.

Results and Discussion.—Prior to the introduction of caustic soda, the effluent pH ranged between 7.3 and 7.4. On February 15, 1950, the day the sodium hydroxide was added, an effluent pH of 12.4 was recorded. During the succeeding 5 days, the effluent pH remained above 11.0. On April 13, 1950—58 days after the addition of NaOH, the effluent pH returned to a normal 7.3. A plot of the daily effluent pH readings is shown in plate 42.

The alkalinity of the effluent during the period followed a similar trend, increasing from a pre-caustic dosed value of about 255 p. p. m. to about 1,500 p. p. m. on the day of the caustic addition. The alkalinity remained above 400 p. p. m. for 9 days, and above 300 p. p. m. for about 4 weeks.

As was noted in the model tank, there was an immediate bulking of sludge after the addition of the caustic soda. For 10 weeks prior to the addition of NaOH, the average depth of sludge was 0.63 foot, and for the 10-week period after the addition of NaOH, the average depth was 0.85 foot. This represents an increase of about one-third of the original volume. The experiment was carried out on a tank which contained a relatively small amount of sludge. If the tank contained a large amount of sludge, which is usually the case when chemical "cleaners" are added, sludge would undoubtedly have been discharged due to the bulking. Such discharge would be damaging to the soil absorption system.

There was no appreciable difference in the removal of suspended solids during the weeks immediately following the caustic soda addition, as indicated on plate 43. The average removal for the 16-week period preceding the addition was approximately 62 percent, while the average of the 16 weeks after the addition was approximately 70 percent.

Several observations lead to the conclusion that caustic soda hampered biological activity. No tank "turnovers," which accompany normal septic tank operation, were observed for five months after addition of the caustic soda. Gas bubbles, which were continually rising in large quantities in other tanks, were scattered and infrequent in this tank.

Interference with digestion, after addition of caustic soda, is also indicated in the rise in the ratio of effluent suspended volatile solids to suspended solids as shown on plate 45. In late July, the ratio dropped to normal. Concurrently with the drop in ratio, gasification, as evidenced by a

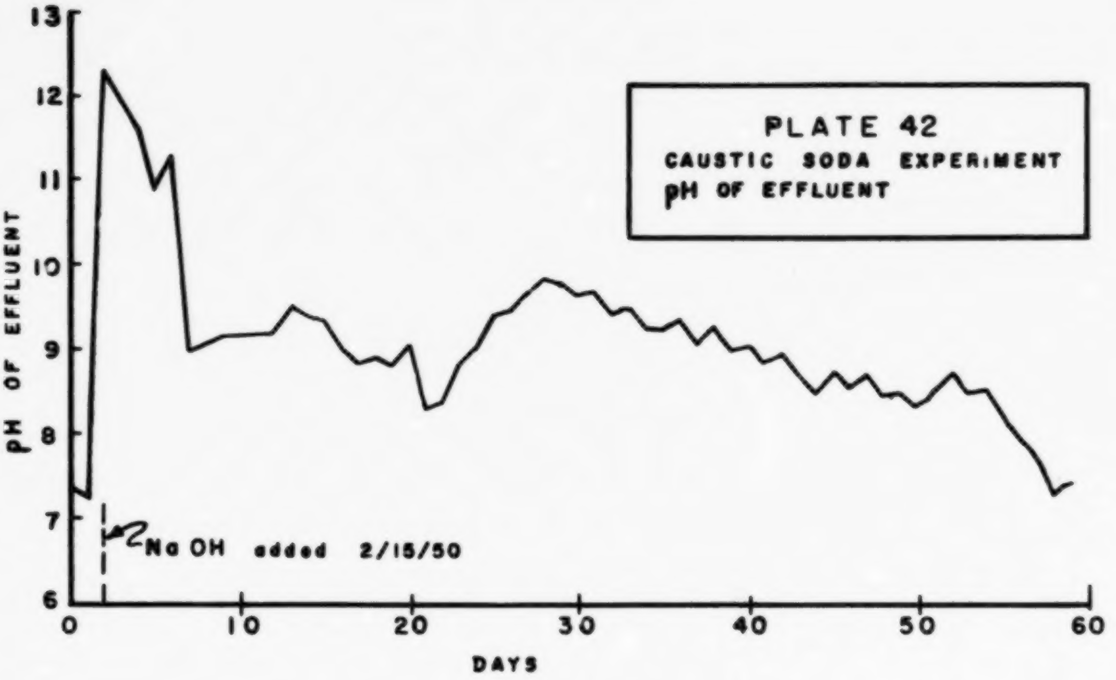

PLATE 42
CAUSTIC SODA EXPERIMENT
pH OF EFFLUENT

large volume of gas bubbles and frequent tank "turnovers," indicated that rapid digestion had restarted.

BOTTLE DIGESTION OF ALKALINE SLUDGE

Several observations during the model tank and full-scale tank study indicated that caustic soda seriously hampered biologic activity. Bottle experiments on sludge digestion, therefore, were conducted to determine more closely the effect of high alkalinity on sludge digestion.

Procedure.—A mixture of 800 ml. of digested sludge and 8 liters of fresh sewage was added to each of six 9-liter bottles. Bottle No. 1 was untreated, for a control. Bottles Nos. 2 to 6 had varying amounts of NaOH added to give a series of pH's in the alkaline range as shown in table 77.

The six bottles were connected to gas-collecting apparatus and the volumes of gas collected over acid brine solution were measured at frequent intervals. Adjustments were made for temperature and atmospheric pressure.

Results and Discussion.—The control, bottle No. 1, produced gas within 2 days of the start of the experiment; bottle No. 2, after 4 days; bottle No. 3, only after 16 days; and bottle No. 5, not until after 41 days. Bottles Nos. 4 and 6 produced no gas for at least 96 days. The pH's at the start and end of the experiment are shown in table 77.

TABLE 77.—NaOH added, pH's, sludge-sewage digestion mixtures

Bottle No.	Grams NaOH added	pH at start	pH at end
1	0	7.2	6.55
2	1.04	9.0	6.65
3	3.36	10.0	6.85
4	4.48	10.5	7.05
5	7.36	11.53	9.40
6	26.16	12.48	12.50

Judged by the lag in gas production, interference with the digestion of a sewage-sludge mixture results from the addition of sodium hydroxide in such concentrations as to raise the pH to 10.0 or higher. A pH of 10.0, under the specific circumstances of this experiment, developed at the equivalent of 1.6 pounds NaOH per 500 gallons sludge-sewage mixture.

SOIL STUDIES

Introduction.—Sodium hydroxide is often used in textural analysis procedures as an aid in soil dispersion, where the intent is to destroy the soil

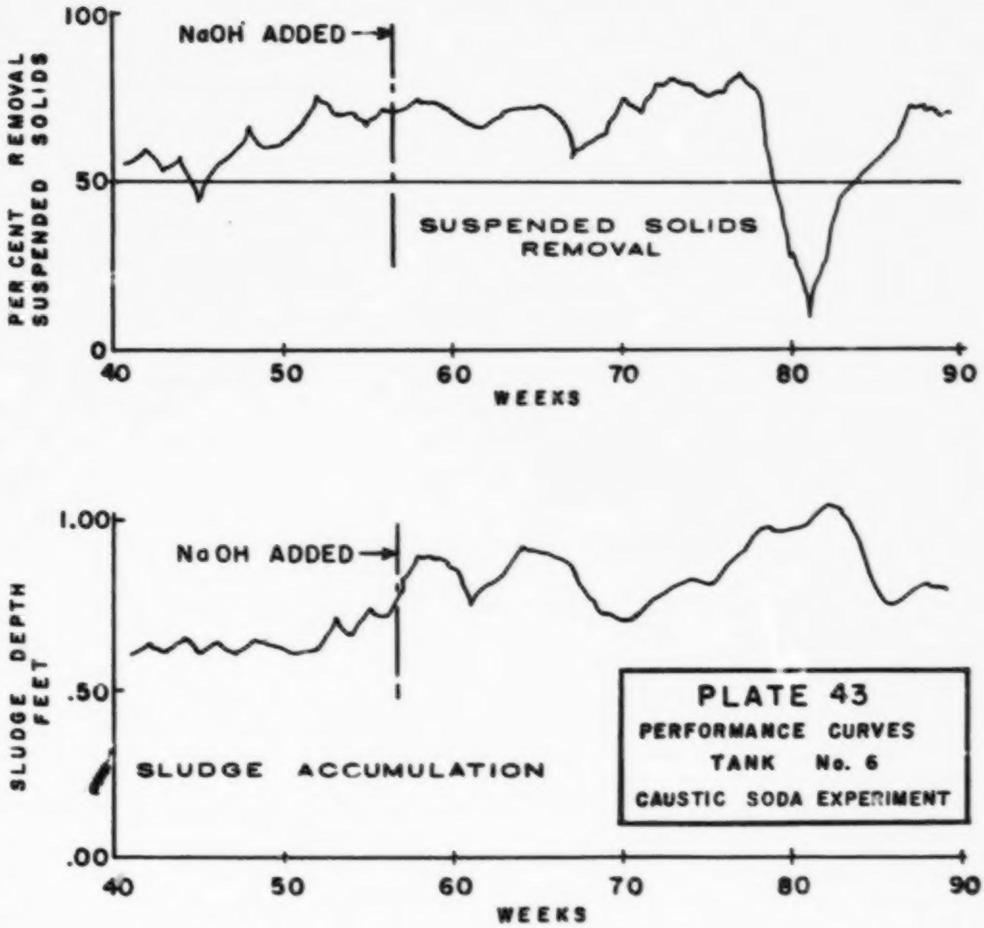

PLATE 43

PERFORMANCE CURVES

TANK No. 6

CAUSTIC SODA EXPERIMENT

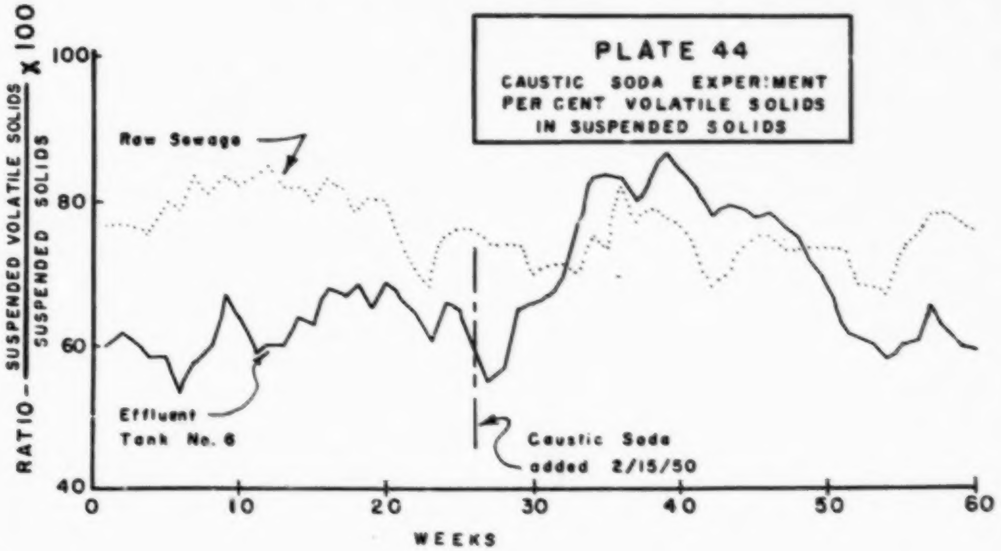

PLATE 44

CAUSTIC SODA EXPERIMENT

PER CENT VOLATILE SOLIDS IN SUSPENDED SOLIDS

structure and to break the soil down into its finest textural components. When a soil is dispersed and the structure destroyed, it becomes more dense and less permeable, thus losing much of its water absorbing capacity.

A typical concentration of sodium hydroxide used in textural analysis procedures (93) is four ml of normal sodium hydroxide in 500 ml of dispersing solution, which is equivalent to 320 p. p. m., or roughly 1.3 pounds per 500 gallons. The concentration of sodium hydroxide resulting from adding a manufacturer's suggested dose of 25 pounds of caustic "cleaner" to a 500-gallon tank, assuming complete mixing, would be approximately 6,000 p. p. m. The effluent pH trend shown on plate 43 and the alkalinity trend indicate that the effluent from a tank so dosed will contain high concentrations for a considerable period of time.

Exploratory studies were made to investigate the probable effects of such effluent on soil absorption properties.

Procedures.—Soil cores were manually packed with 8 to 14 mesh soil aggregates sieved from a Brookston silt loam soil, using glass tubes 3 cm. in diameter and 20 cm. long. Soil was added in three increments, each uniformly packed by rodding and tamping. Soil core was then connected to a constant level device and allowed to wet up slowly. Tapwater was then dosed to the cores for several days to obtain a basic rate for each core before effluent dosing treatments were started.

Effluent dosings were then made twice daily, at 10 a. m. and at 4 p. m. A 6-cm. head of dosing solution, placed on each core, was permitted to drop to 1 cm., measuring volumes of percolate at five-minute intervals. Comparative rates were based on daily averages. A static head of 1 cm. of fluid was maintained on the cores between dosings. The temperature of the effluents over the period of the study varied from 21° to 25° C.

Three experiments were conducted: (1) using supernatant effluent from the bottle digestion experiments described above, (2) using glass wool filtered septic tank effluent with varying concentrations of NaOH added, and (3) using fresh filtered septic tank effluent with varying concentrations of KOH added. At the conclusion of core dosing, aggregate analysis of each soil core was made.

Results and Discussion.—Dosing of soil cores with supernatant liquor from the bottle digestion experiments gave rather dramatic results. The supernatant liquor having an original pH of 12.48, table 77, caused almost immediate clogging. Within a matter of minutes, percolation stopped, whereas original percolation rates had been approximately 150 ml. per hour. The soil aggregates during this time seemed to merge and form a dense mass with little visible pore space. All supernatant having an original pH of 10.0 or greater caused similar effects.

The second experiment was run in order to determine minimum concentrations of sodium hydroxide in septic tank effluent that might be damaging to soil absorption properties. The amounts of sodium hydroxide added, the relative soil clogging, and the resultant aggregate stabilities are shown in table 78.

TABLE 78.—Effect of effluents containing sodium hydroxide on soil clogging and aggregate stability

Core No.	Amount of NaOH added to effluent (p. p. m.)	Soil aggregate stability (percent)	Relative soil[1] clogging after 30 days (percent)
1	2, 000	10. 9	100. 0
2	1, 500	13. 4	97. 8
3	1, 000	15. 0	96. 0
4	750	17. 6	91. 8
5	500	24. 9	80. 0
6	380	33. 1	20. 0
7	250	47. 9	0
8	180	54. 5	0
9	120	49. 4	0
10	0	56. 6	0

[1] Relative soil clogging $= 100 - 100 \times \frac{\text{rate after 30 days}}{\text{original rate}}$.

Effluents containing 500 p. p. m. or greater of sodium hydroxide showed the same rapid clogging as caused by the bottle experiment supernatants. A concentration of 380 p. p. m. caused less rapid, but significant, clogging. It may also be noted in table 78, as might be expected, that the degree of clogging is directly related to the aggregate stability, the greater the clogging, the less stable the aggregates.

The above experiment was repeated using potassium hydroxide instead of sodium hydroxide. The results are shown in table 79. Although the damaging effect of potassium hydroxide was not so great as that of the sodium hydroxide, there was clogging in concentrations as low as 750 p. p. m. together with similar detrimental effects on soil structure.

TABLE 79.—Effect of effluents containing potassium hydroxide on soil clogging and aggregate stability

Core No.	Amount of KOH added to effluent (p. p. m.)	Soil aggregate stability (percent)	Relative soil[1] clogging after 30 days (percent)
1	2, 000	34. 6	53. 2
2	1, 500	29. 7	53. 5
3	1, 000	43. 9	47. 5
4	750	51. 5	5. 5
5	500	52. 9	0
6	380	51. 3	0
7	250	56. 9	0
8	180	53. 8	0
9	120	47. 8	0
10	0	51. 2	0

[1] Relative soil clogging $=100-100\times\frac{\text{rate after 30 days}}{\text{original rate}}$.

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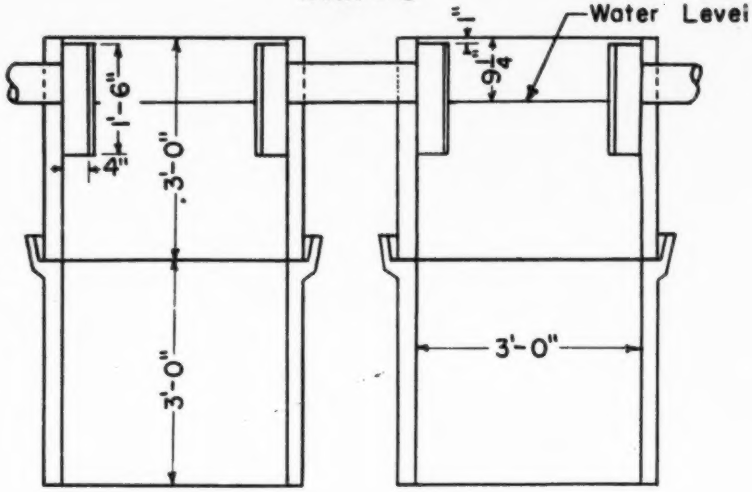
Appendix

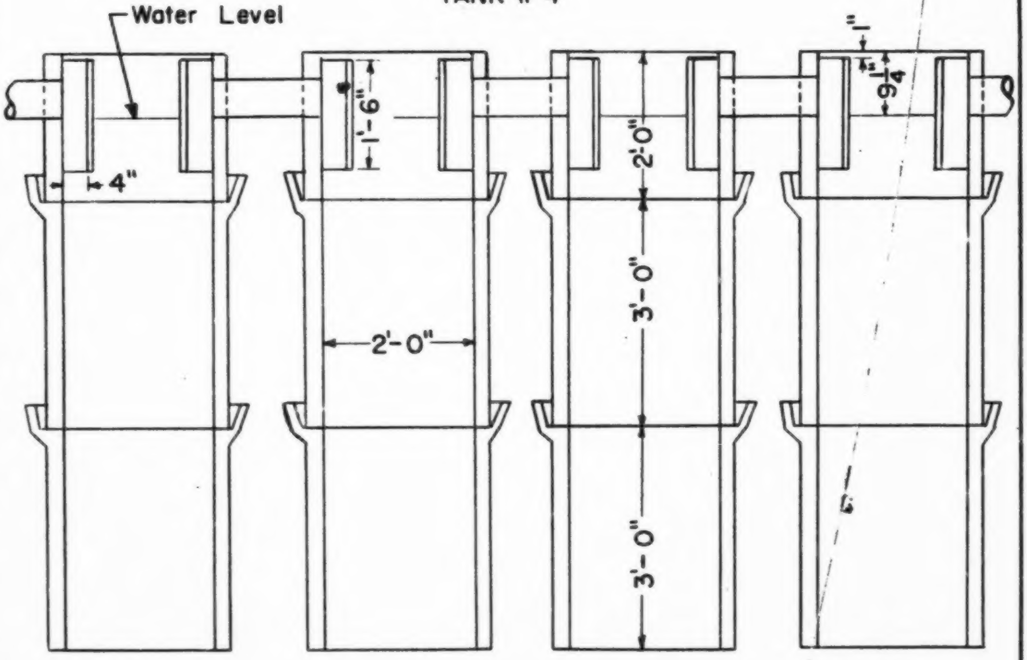
VERTICAL CYLINDRICAL TANKS

TANK # 3



1"
Water Level
9 1/4"
1'-6"
4"
3'-0"
3'-0"
3'-0"

TANK # 4

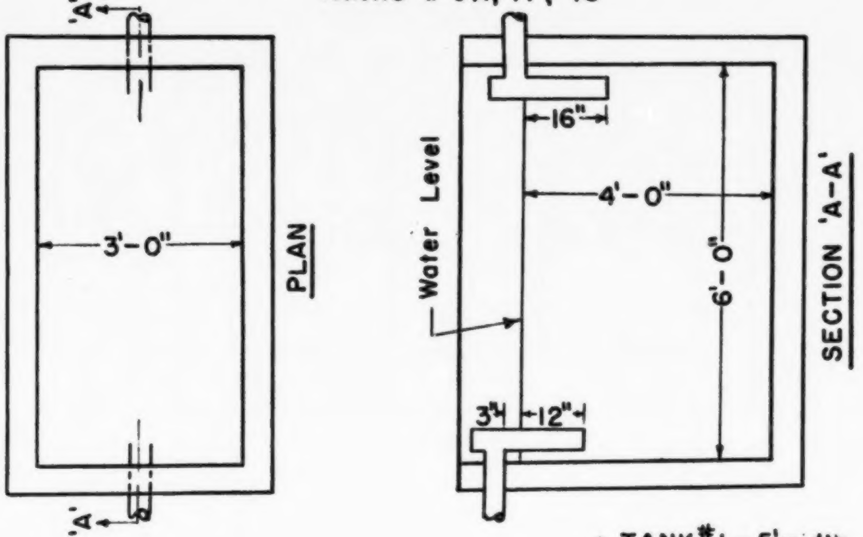


Water Level
1"
9 1/4"
1'-6"
4"
2'-0"
2'-0"
3'-0"
3'-0"

PLATE 45

RECTANGULAR TANKS

TANKS # 9A, 17,* 18


'A'
'A'
3'-0"
PLAN
16"
4'-0"
6'-0"
Water Level
3/4"
12"
SECTION 'A-A'

∘ TANK # 1 – 5' width,
5' depth & 11' length

*Outlet Penetration = 13"

TANKS # 7A, 7P

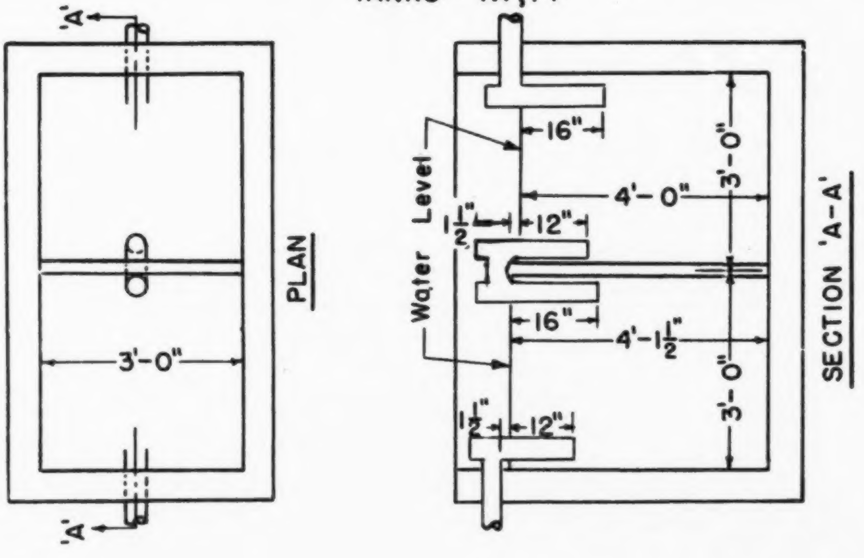
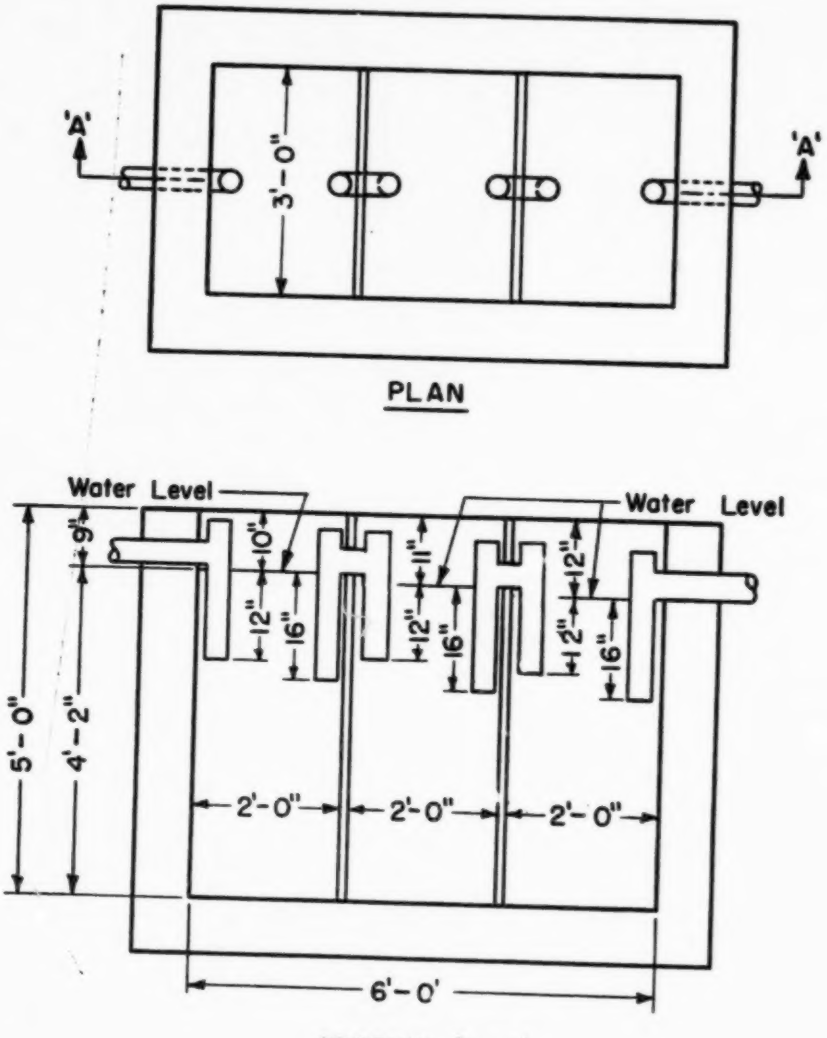

'A'
'A'
3'-0"
PLAN
16"
4'-0"
3'-0"
Water Level
1½"
12"
16"
4'-1½"
3'-0"
1½"
12"
SECTION 'A-A'

PLATE 46

RECTANGULAR TANKS

TANK #19



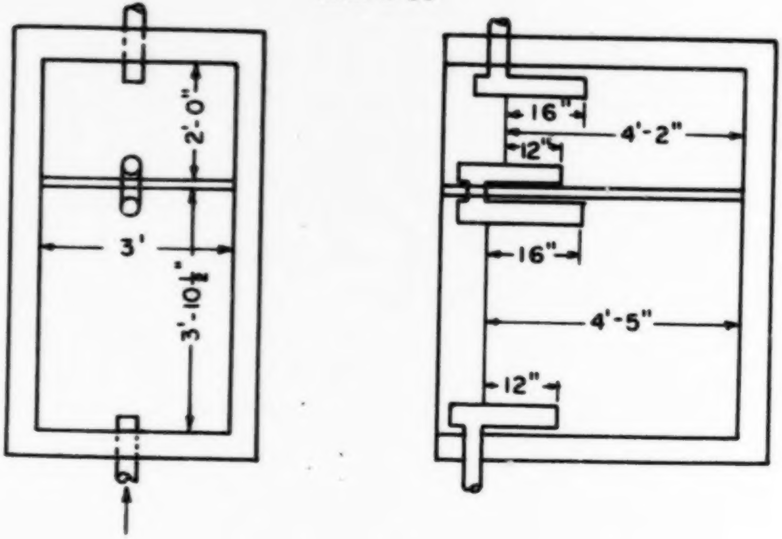
'A'
'A'
3'-0"
PLAN
Water Level
Water Level
9"
10"
11"
12"
12"
16"
12"
16"
12"
16"
5'-0"
4'-2"
2'-0"
2'-0"
2'-0"
6'-0'

SECTION 'A-A'

PLATE 47

RECTANGULAR TANKS

TANK # 9P


2'-0"
3'
3'-10½"
16"
4'-2"
12"
16"
4'-5"
12"

TANK # 19P

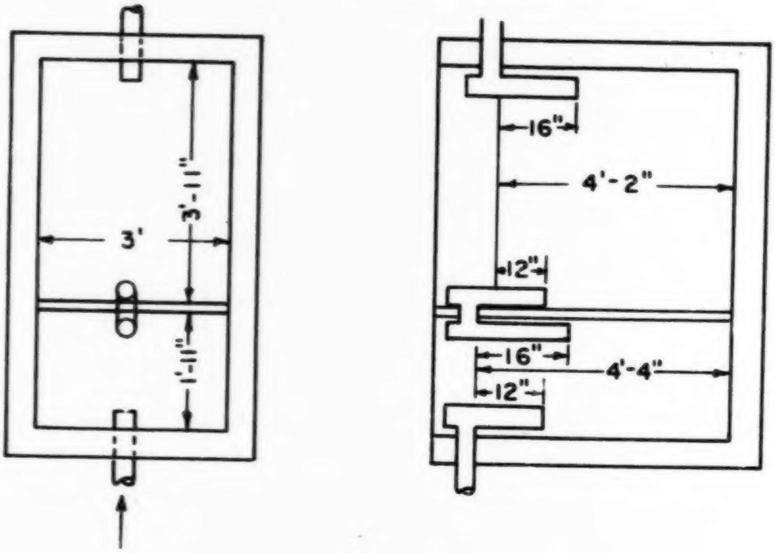
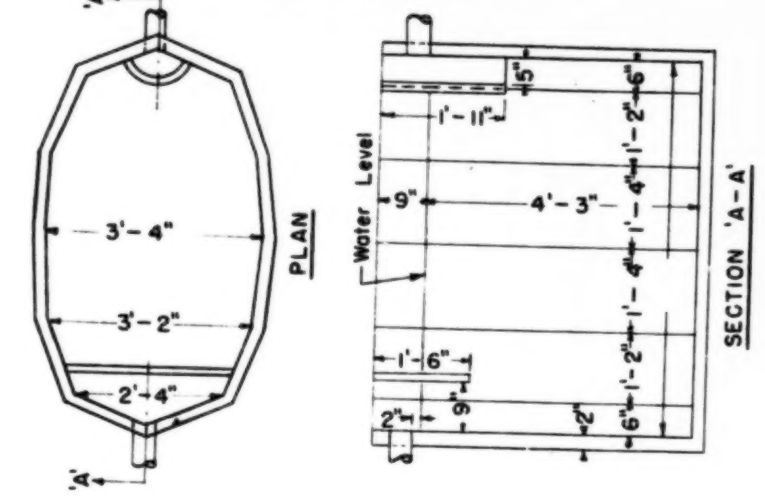

3'-11"
3'
1'-11"
16"
4'-2"
12"
16"
4'-4"
12"

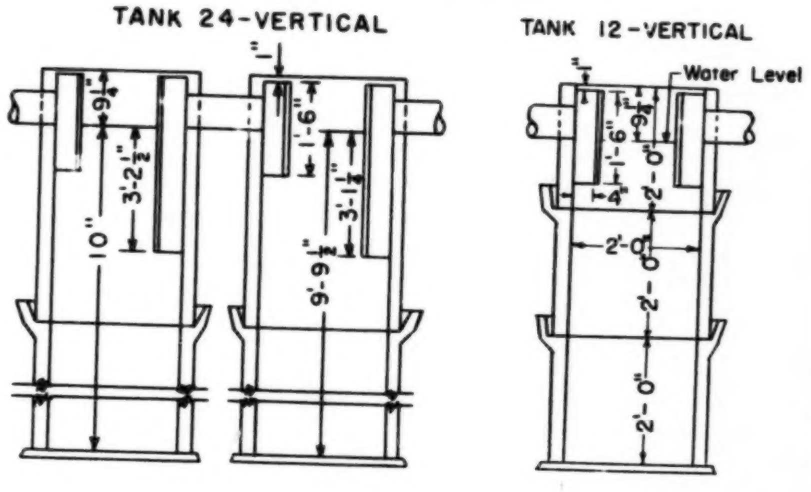
PLATE 48

TANK #5 - OVAL SHAPED



'A'
PLAN
3'-4"
3'-2"
2'-4"
'A'
Water Level
9"
4'-3"
1'-11"
5"
6"
1'-2"
1'-4"
1'-4"
1'-2"
6"
1'-6"
9"
2"
2"
SECTION 'A-A'

CYLINDRICAL TANKS

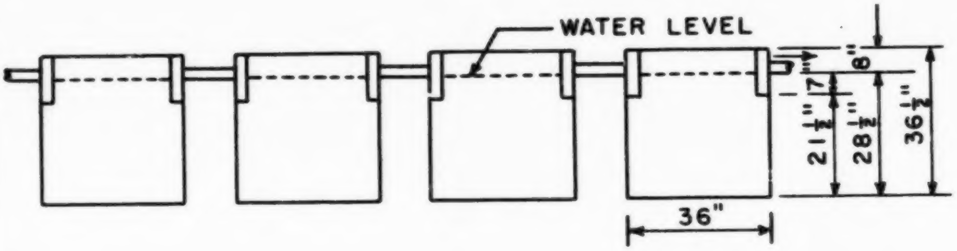


TANK 24-VERTICAL
9¼"
3'-2½"
10"
1"
1'-6"
3'-1½"
9'-9½"
TANK 12-VERTICAL
1"
Water Level
1½"
9¼"
1'-6"
2'-0"
4"
2'-0"
2'-0"
2'-0"
2'-0"

PLATE 49

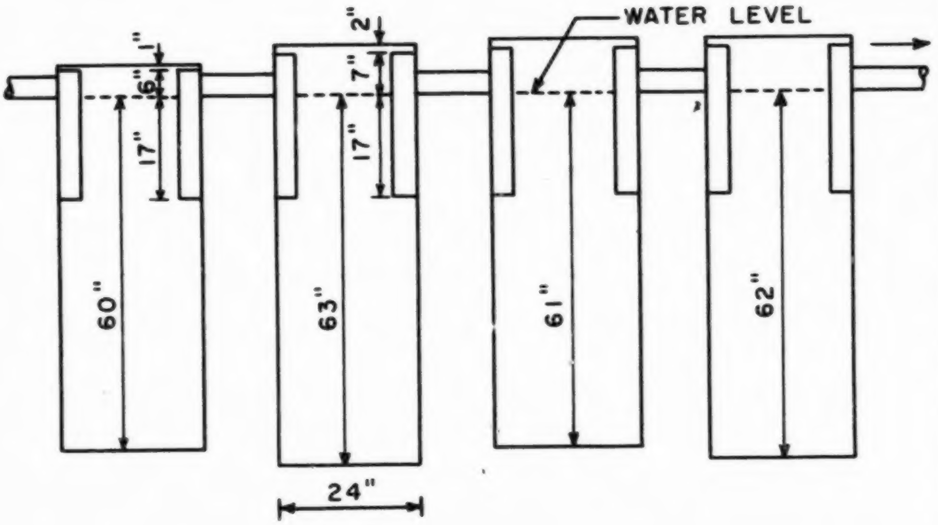
VERTICAL CYLINDRICAL TANKS

TANK # 3D



WATER LEVEL
8"
17"
21½"
28½"
36½"
36"

TANK # 4D

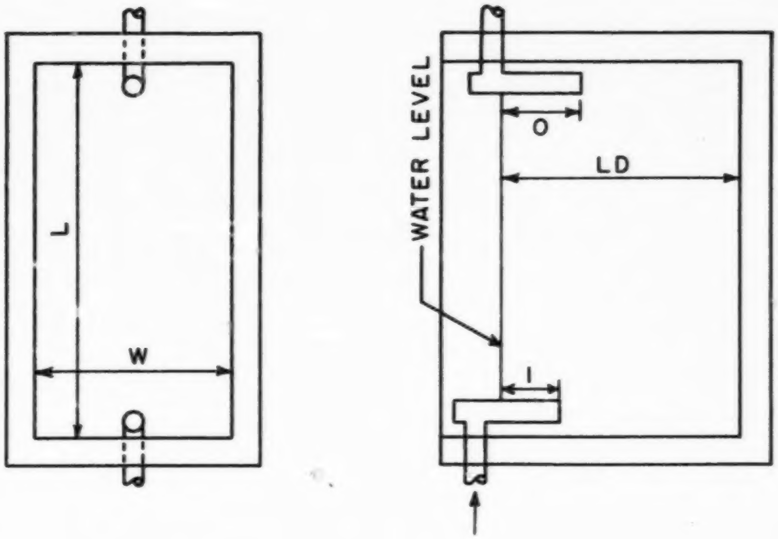


WATER LEVEL
1"
6"
2"
7"
17"
17"
60"
63"
61"
62"
24"

PLATE 50

RECTANGULAR TANKS

TANKS # 20, 21, 22, 23, (Depth Study)



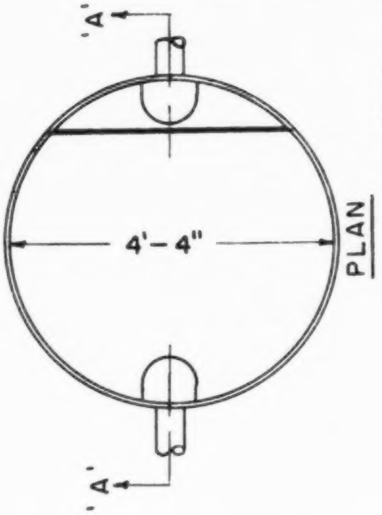
L
W
WATER LEVEL
O
LD
I

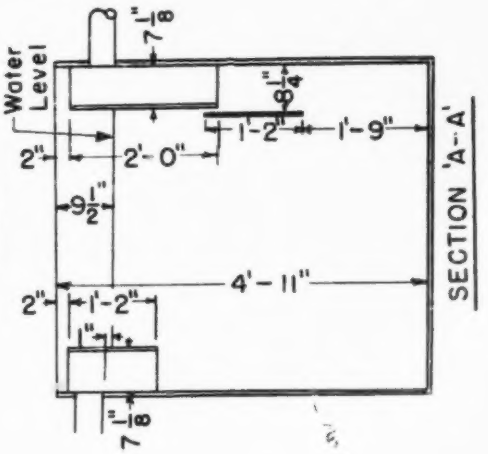
TANK NO.	DIMENSIONS				
	L ft.	W ft.	LD in.	I in.	O in.
20	7.50	3.75	28.5	6	6.00
21	5.00	2.50	64.0	6	18.75
22	5.85	2.92	48.0	6	13.00
23	6.67	3.33	36.0	6	8.62

PLATE 51

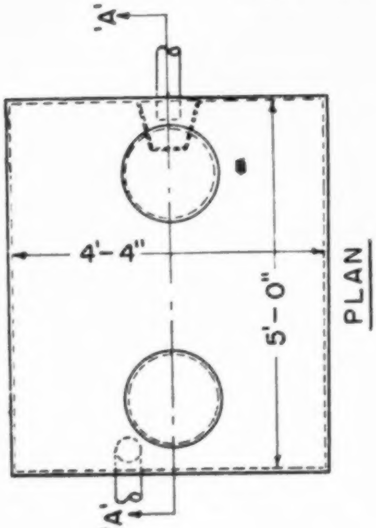
CYLINDRICAL TANKS

TANK #6 S VERTICAL




7 1/8"
Water Level
8 1/4"
1'-2"
1'-9"
2"
2'-0"
9 1/2"
4'-11"
2"
1'-2"
1"
7 1/8"
SECTION 'A-A'

TANK #8 - HORIZONTAL


'A'
4'-4"
5'-0"
PLAN
'A'

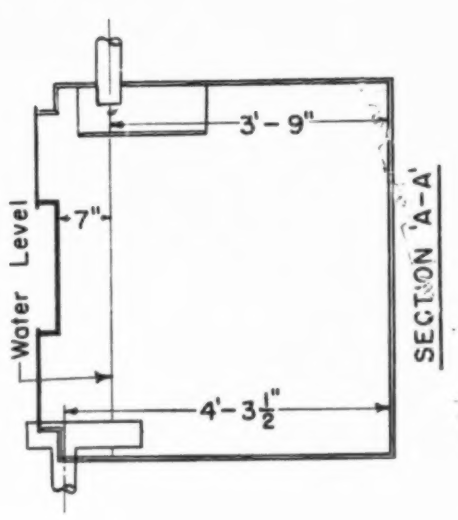

3'-9"
7"
Water Level
4'-3 1/2"
SECTION 'A-A'

PLATE 52

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